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ENCODING VARIABILITY AND THE EFFECT OF SPACING OF REPETITIONS IN CONTINUOUS RECOGNITION MEMORY

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Two experiments were conducted to test the variable encoding theory of the spacing effect. The distance between two repetitions and the contextual environment affecting probability of getting a same or different code were orthogonally varied in a modified Shepard-Teghtsoonian (1961) continuous recognition list. The target items were homographs and each of them was paired with either a biasing context word (a word inducing a particular meaning of the target) or a neutral context word. Upon presentation of a context-target doublet, Ss were to indicate both the relatedness between the two items and the frequency of prior occurrences for each of them. A target word occurred three times, each with one of the three contexts: X (inducing one meaning of the target), Y (inducing the alternate meaning), and N (neutral). The orders of these contexts were XXX, XXY, XYX, XYY, XXN, or NNN for the three presentations. The distance between the first and second occurrences was either 8, 20, or 60 intervening pairs; that between second and third was always 60. The spacing effect was observed in judgments of frequency in the NNN and the XX- conditions. The XY- conditions did not show any effect of spacing. The functions were generally high and flat.

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PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human information processing stress factors, supported by the Human Resources Research Office of the Advanced Research Projects Agency, under Order Nos. 461 and 1949, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract Nos. AF 49(638)-1736 and F44620-72-C-0019, respectively.

This report was also a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1972. The doctoral dissertation committee was: Drs. E. J. Martin, Chairman, R. A. Bjork, A. W. Melton, and M. H. O'Malley.

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ABSTRACT

There is evidence showing that when a to-be-remembered item is presented to a subject twice, memory for that item changes as a function of the distance between the two repetitions. Up to some limit, memory becomes better the greater this distance. This improvement in memory defines the spacing effect.

Two experiments were conducted to test the variable encoding theory of the spacing effect. One version of the theory, the multiple-code version, states that the spacing effect is caused by a higher probability, associated with spaced repetitions, of getting a different code for a same to-be-remembered-item in its second occurrence.

In the experiments, the distance between two repetitions and the contextual environment affecting probability of getting a same or different code were orthogonally varied in a modified Shepard-Teghtsoonian (1961) continuous recognition list. The target items were homographs and each of them was paired with either a biasing context word (a word inducing a particular meaning of the target) or a neutral context word. Upon presentation of a context-target doublet, Ss were to indicate both the relatedness between the two items and the frequency of prior occurrences for each of them. A target word occurred three times, each with one of the three contexts: X (inducing one meaning of the target), Y (inducing the alternate meaning), and N (neutral). The orders of these contexts were XXX, XXY, XYX, XYY, XXN, XYN, or NNN for the three presentations. In a second experiment, only XXN, XYN, and NNN were included. The distance between the first and second occurrences was either 8, 20, or 60 intervening pairs, and that between second and third was always 60.

The spacing effect was observed in judgments of frequency in the NNN and the XX- conditions. The XY- conditions did not show any effect of spacing. The functions were generally high and flat.

Multiple encodings of an item thus leads to higher judged frequency and hence a stronger representation of that item in memory. However, on the basis of the spacing effects found in the XX- conditions and their similarity to NNN, it is concluded that encoding variability in the sense of getting alternate meanings of a to-be-remembered-item is not the factor that actually produces the spacing effect. It is further suggested that it is variability of contextual cues associated to a code rather than variability in encodings that may be responsible for the spacing effect as observed.

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CHAPTER I

INTRODUCTION

Consider the following sequence of events. A to-be-remembered item (TBRI) is presented to a subject (S) for study for the first time (P_1). Then there follows an interval filled with other activities, be they rehearsal-preventing activities or presentations or tests of some other TBRIs. The same TBRI is presented again for a second time (P_2). This is also followed by an activity-filled interval which terminates with a test for retention (T) of the given TBRI. We shall call the first interval the interpresentation interval (IPI) and the second the retention interval (RI). Let *t* stand for time. This sequence of events can be graphically presented as this,

$$\underline{t} \longrightarrow$$

$$, \underline{P_1}, \underline{\quad IPI \quad}, \underline{P_2}, \underline{\quad RI \quad}, \underline{\;T\;},$$

In this sequence, if P_1, P_2, and IPI are held constant and RI is varied, the relationship between T and RI is simply the retention function of a TBRI presented twice. Ever since the time of Ebbinghaus (1885), that T is a decelerating decreasing function of RI has been established in a variety of situations. On the other hand, if IPI is varied and the other events held constant, the relationship between T and IPI defines the spacing function. Unlike the retention function, this spacing function has been found to be increasing with increasing IPI.

That T is an increasing function of IPI seems to be as general as the decreasing retention function. It has been found in paired-associate learning, short-term retention for individual items, and free recall learning. The empirical spacing effects in these situations have been reviewed by Bjork (1970) and Melton (1970). The increasing spacing function was also found in frequency judgment (Hintzman, 1969a), and in recognition memory with both recognition time measure (Hintzman, 1969b) and recognition frequency measure (Kintsch, 1966; Underwood, 1969b).

There are also certain specificities of the spacing effect, two of which were noted by Bjork (1966). First, there is a limit on the age of a TBRI to benefit from spaced repetitions. That is, the spacing function rises to some optimal level at a certain IPI and then declines. Although this concave downward relationship between T and IPI was documented in a continuous paired-associate learning situation only (Peterson, Wampler, Kirkpatrick, & Saltzman, 1963; Young, 1966), it is very reasonable to expect this relation to hold in other situations as well, if IPIs in those situations are extended long enough.

Second, there is some evidence that the effect of IPI is interactive with RI. For shorter RI, the relation between T and IPI is the reverse of the usual spacing function; that is, shorter IPI results in better performance at T (Peterson, Saltzman, Hillner, & Land, 1962; Rumelhart, 1967). However, the evidence is rather meager and the extent to which shorter IPI produces better T performance is not of a satisfactorily sufficient magnitude.

Furthermore, there are situations, in free recall, in which the spacing effect is not found (Waugh, 1963, 1970). In some other situations if it is found at all the function is of a different sort, that is, a discrete jump from one level of performance with IPI = 0 to a higher level when IPI > 0. For all non-zero IPIs, the performance levels are the same (Underwood, 1969b). Exactly what determines Waugh's and Underwood's seemingly variant phenomena is still a matter of speculation. For Waugh's failure to find the spacing effect, Melton (1970) has suggested that it may be due to several procedural factors involved in Waugh's experiments. Among these factors may be rate and mode of presentation (fast and auditory), and short and well structured lists. For the Underwood discrete-jump finding, it is also likely to be a result of procedural variations from those in which a continuous spacing function was found. Besides varying IPI, Underwood (1969b) varied the frequency of occurrence of a TBRI from 1 to 4, instead of just once or twice before testing as in a standard spacing-of-repetitions experiment.

Theories of the Spacing Effect

There are at present a number of different theories proposed to account for the spacing effect. All these theories can be categorized into two general classes according to the where of the effect as assumed by each theory, that is, the effect occurs during IPI or at P_2. Within each of these two loci, theories differ further in the how of the effect. At each locus, various processes can be proposed to produce the same observed effect of spacing.

The two loci, IPI and P_2, are of course by no means exhaustive of all possibilities. RI may be involved, but it is not taken into consideration by any of the theories. The exclusion of P_1 seems more reasonable for the reason that as P_1, S is incapable of prophesying the kind of repetition he is going to get for that item and hence there is no ground for him to act differently at P_1. As for T, the exclusion is also reasonable. As stated earlier, the spacing effect has been found in a variety of T conditions. These conditions range from retrieval of the TBRI with minimal amount of cueing as in recall of individual items in the Peterson and Peterson (1959) paradigm, to retrieval with maximal amount of cueing as in recognition memory experiments.

Before examining the theories, it should be pointed out that although similar spacing effects have been found in different situations, the underlying causes may not be the same. We may need different theories in different situations. This suspicion has been voiced by Greeno (1970) and Melton (1970). Indeed, some differences in the magnitude of improvement resulting from a spaced repetition, as well as in the optimal length of IPI to produce the greatest spacing effect, have been documented (e.g., Melton, 1970).

However, it would be premature at the present stage of inquiry to reject the idea of having one single theory for all different situations. The differences that have been noted may reflect only procedural variations. For instance, RI in free recall situations cannot be as well controlled as that in the Peterson-Peterson paradigm

or continuous paired-associate learning situations, due to uncontrolled output orders and time allowed for recall. Another procedural difference is in the amount of information processing demanded in each task. Counting backward by threes at a high speed in the Peterson-Peterson paradigm may be more capacity taxing than study and test of other items in a continuous paired-associate learning situation, which may be in turn more difficult than just mere study in free recall learning studies. If this should prove to be the case, it will also explain some of the observed difference in the optimal IPI length for a maximal spacing effect.

The four experimental situations involved in the effect of spacing can be also thought of as different in the retrieval processes. Retrieval of individual items in the Peterson-Peterson paradigm involves minimal cueing whereas that in the recognition memory situation is maximal. For the other two, that is, paired-associate and free recall, the amount of cueing can be placed somewhere in between along the amount-of-cueing continuum. But as noted before, the spacing effect is independent of output methods and hence attention can be turned to the input phase of the memorial process.

In the input phase, S has to encode each TBRI, or set of TBRIs, as presented to him. This process is common across different situations. What is different is in what the S must do with the item further in order to meet task demands. Maximal associative integration among the TBRIs may be a must if he is asked to study for free recall. That the TBRIs are organized into groups in free recall learning can

be readily inferred from systematic output contiguity of items based on various sources. Among these sources are (a) items belonging to the same conceptual category (Bousfield, 1953), (b) items that are associatively related (Jenkins & Russell, 1952), (c) items presented contiguously in the input list (Tulving & Patkau, 1962), and (d) items recalled next to each other in the preceding recall of the same list (Tulving, 1962).

If the task is paired-associate learning, the amount of inter-TBRI associative integration may be less. Provided the response term is already well integrated, the organization that involves is mostly association between the response term and its stimulus. Provided, again, each TBRI is already well integrated, associative organization may be at its minimum if the task is a Peterson-Peterson type memory or recognition memory.

Thus in the input phase, two separate processes can be identified, encoding of individual TBRIs and associative integration or organization of these TBRIs. The first process is common across all four different experimental situations whereas the second may be quantitatively different among them. If the encoding phase is where the spacing effect is, then only one theory is needed for all situations. And if the effect lies in the organization phase, multiple theories are still not necessary. On the contrary, by assuming one single theory across all situations differing in amount of organization, differences in the magnitude of the spacing effect found in these various situations can also be accounted for. At present, if a choice is to be made at all between single theory and multiple theories it will have to be made on the basis of faith rather than something empirical. For parsimony,

it will be assumed that there is a single theory for all these different situations. This assumption will be entertained until empirical evidence dictates otherwise.

<u>Locus IPI</u>: <u>Consolidation Theory</u>

Theories that attribute the spacing effect to something occurring during IPI have Hebb's (1949) dual-trace postulate of perception and learning as their basic assumption. According to Hebb, the reactions of an organism to a stimulus impinging upon that organism are two-fold. First, an active reverberating neural circuit is activated. This reverberating circuit is assumed to outlast the existence of the stimulus event and decay rather rapidly, that is, in the order of 1 to 5 to 10 sec in man (Hebb, 1949, p. 143). Second, as a result of this temporary reverberatory activity, there is a structural alteration or consolidation of the nervous system which represents a more permanent memory of the event.

The relationship between the long-term representation of an event and the short-term activity trace that induces it can be conceived as all-or-none at the onset of the short-term activity trace. Another type of relationship can be that as long as there is a short-term activity trace, the long-term trace will be built up gradually.
In order to account for the spacing effect, a gradual relationship, if there is a relationship at all, is a necessity. The nature of this gradual relationship is not important in this connection. It can be a gradual increase in the long-term trace strength over time, or within a given epoch of the short-term activity time course there is some probability that the long-term trace will be produced and these

probabilities accumulate across epochs. Either way, the important idea is that long-term representations depend on the time duration, according to some function, of the short-term representations.

Working hypotheses for the spacing effect derived from Hebb's theory have been given by various theorists. Among them are Landauer (1969), Peterson (1966), and Wickelgren (1970). Since these working hypotheses are basically the same, only Landauer's version will be focused upon. According to Landauer, a stimulus triggers a temporary reverberating activity, and "if the reverberating activity were at a maximum level immediately following a learning trial, a second occurrence of the stimulating event could not produce as much additional reverberating activity as did the first" (p. 84). This hypothetical situation can be represented graphically as in Figure 1.

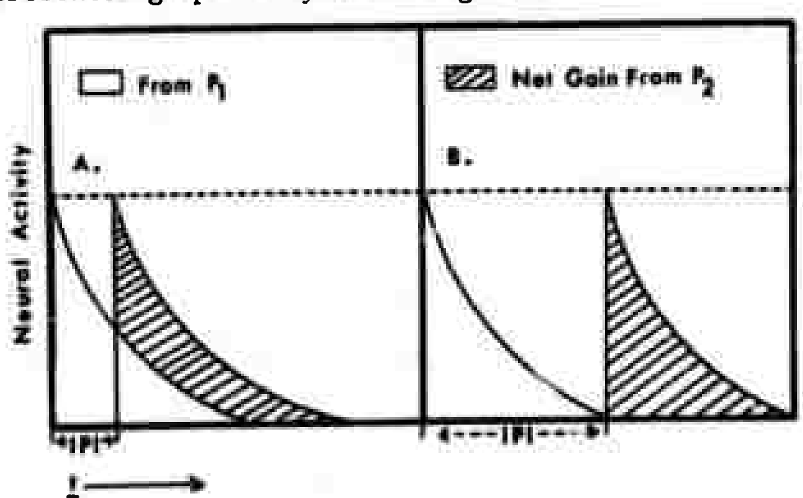

Fig. 1. Postulated time course of short-term reverberating activities and their combination as a result of repetitions (from Landauer, 1969).

Landauer assumes the amount of consolidation to be a function of both level and duration of the reverberating activity. This amount, then, can be represented by the blank areas in panels A and B in Figure 1. The shaded area represents the net gain in long-term memory as a result of a P_2. The sum of the blank and shaded areas determines the total amount of consolidation for two presentations. Thus the longer the IPI, the greater will be the amount of consolidation. The increase will reach an asymptote at a certain IPI length, as in panel B.

Although a duration of 1 to 5 to 10 sec has been suggested by Hebb (1949) as the persistence time for the reverberating activity, the empirical duration remains to be established.

There are a number of difficulties involved in determining empirically the persistence time for a TBRI. In order to prevent rehearsal some intervening activity is necessary. The introduction of rehearsal preventing activity also introduces interference. Nature of the TBRI, level of difficulty of the intervening activity, as well as its similarity to the TBRI, have been shown to affect short-term retention (Melton, 1963; Posner & Rossman, 1963; Ligon, 1968). Thus, any time duration established is necessarily relative to the nature of intervening activity and its similarity to the TBRI. This suggests that different task situations will have different time courses of consolidation.

In an attempt to determine the consolidation time course in the continuous paired-associate learning situation, Peterson (1966) presented a series of 8 to 12 paired associates at a 2-sec rate. The procedure is similar to that in which the spacing effect was found.

The S was asked to free recall the pairs after a varied number of pairs had been presented. Probability of recall was found to decrease with increasing number of intervening pairs and the asymptote starts at 4 intervening pairs, or 8 sec. Since there was no control in the output order, this duration is necessarily underestimated due to possible output interference from other items. Nevertheless, this 8 sec interval has been found to produce the asymptotic spacing effect by both Peterson et al. (1963) and Young (1966).

In the free recall situation, the recency effect is customarily thought of as resulting from the persistence of events recently perceived. This recency effect is usually gone with presentation of 7 or 8 other items (Murdock, 1963). When the intervening activity is of a different sort, such as counting backward, and thus producing less interference, a duration of 30 sec was found sufficient to completely wash out the recency effect (Glanzer & Cunitz, 1966; Postman & Phillips, 1965). This suggests that in free recall situations, amount of consolidation should reach its maximum with 7 or 8 intervening items, or a duration of 30 sec filled with an unrelated activity.

However, in free recall experiments, increasing recall was still observed when IFI was increased to 20 and 40 intervening items (Madigan, 1969; Melton, 1970). With a rate of 4.3 sec per item (Melton, 1970), this duration is 86 and 173 sec, respectively. Both Madigan (1969) and Melton (1970) take this observation as evidence against theories that postulate the persistence of the P_1 event at P_2 as the determining factor of the spacing effect, of which the consolidation theory is one.

In an experiment designed explicitly to test the consolidation theory, Bjork and Allen (1970) varied RI and the level of difficulty of the intervening activity during IPI orthogonally. The auxilliary assumption involved in this connection is that a difficult intervening task disrupts consolidation more than does an easy task. Thus, with IPI kept constant, performance at the end of IPI for the difficult task condition will be worse than that for the easy task condition. With a word-trigram as a stimulus and fast or slow digit naming as an intervening task, this prediction was confirmed. With both IPI = 3 sec and IPI = 12 sec, recall in the difficult task condition was worse than that in the easy task. However, when a P_2 was added to both conditions, the relationship reversed. The difficult task condition had better recall at T than the easy task. This is counter to what should be expected from the consolidation theory. That is, whatever is the result of having a P_2 is added to both conditions as a constant and hence the difficult task condition should have remained inferior to the easy task condition.

It should be pointed out that the term consolidation can be thought of as either rehearsal to maintain an item in memory or autonomous persistence of some neural event. Regardless of how this term is interpreted, the consolidation theory is difficult to reconcile with the Bjork and Allen data. As rehearsal, a difficult intervening task should <u>prevent</u> consolidation more than an easier task and thus a poorer performance at T. As autonomous persistence, a difficult task should <u>disrupt</u> consolidation more and hence the same prediction is borne out. But this poorer performance prediction is clearly contradicted by the data.

Locus P_2

If the locus of the spacing effect is at P_2, there are two possibilities. First, it could be that in the shorter IPI condition, the S fails to utilize a P_2 as effectively as it normally should be. This may be due to a failure of attention or learning effort, during P_2, for items immediately repeating themselves. The second possibility is that in both short and long IPIs, Ss utilize P_2 fully but longer IPIs provide better opportunity for getting better or richer codes for the repeated TBRIs.

There are several theories that postulate the first possibility as the explanatory mechanism of the spacing effect. Among them are multistate Markov forgetting models of Atkinson and Crothers (1964) and Bjork (1966), Atkinson and Shiffrin's (1968) buffer model, and the conservation of information-processing capacity hypothesis of Greeno (1970). All these theories make a distinction, as does the consolidation theory, between a short-term persistence and a relatively more permanent long-term retention of a TBRI.

Locus P_2: Markov Forgetting Models

The multistate-Markov forgetting model as proposed by Atkinson and Crothers (1964) postulates that as a result of P_1, a TBRI will be absorbed from a forgotten or unlearned state (F) into a permanent long-term memory or learned state (L) with a probability a. If the item does not enter L, it will reside in a short-term retention state (S), with probability 1-a. An item in state S has a probability of f to be forgotten, enter state F, during subsequent presentation of another

item. With a probability of $1-f$ the item will remain in state S. If an item is either learned in L, or in short-term memory, in S, a correct response will be given. If an item is forgotten, a correct response can occur only when the S guesses correctly, with a guessing probability g. If we let b be the probability that, at P_2, an item in state S will enter state L, we have the following transition matrix and response probabilities.

Transition Matrix

After P_2

Response Rule

Pr(Correct)

End of IPI and Before P_2

$$\begin{array}{cc} & \begin{array}{ccc} L & S & F \end{array} \\ \begin{array}{c} L \\ S \\ F \end{array} & \begin{bmatrix} 1 & 0 & 0 \\ b & (1-b)(1-f) & (1-b)f \\ a & (1-a)(1-f) & (1-a)f \end{bmatrix} \end{array} \qquad \begin{bmatrix} 1 \\ 1 \\ g \end{bmatrix}$$

This matrix is adapted from Atkinson and Crothers' (1964) LS-2 model. It is actually the product of two matrices, one describing learning transition and the other forgetting transition from one state to another. By assuming, as did Bjork (1966), that there is an increasing probability for items residing in S to be absorbed back to F (f increases) in subsequent presentations of other items, and that the absorbing probabilities from S and F into L are different such that $b < a$, the model yields a spacing effect function. With shorter IPIs, the probability is higher that a TBRI will remain in S, and hence a lower probability for learning that item at P_2. On the other hand, if the item is forgotten, as is more likely with longer IPIs, the

learning probability is higher and hence a beneficial effect for spaced repetitions.

The Markov forgetting models as described do not predict a decline in performance when IPI is beyond its optimal length. This is due to the assumptions that once a TBRI is absorbed in L it will remain there permanently and that retrieval from L is always perfect. Either one of these two assumptions may be modified in order to account for the decline. That is, residence of a TBRI in L may be assumed to be less than permanent. There is some probability of loss (less than $\underline{f}$, of course) from long-term storage. Equally possible is the response rule that retrieval from L may fail and this failure is a function of RI.

Locus P_2: Buffer Model

This latter possibility is incorporated into a model proposed by Atkinson and Shiffrin (1968). The model assumes a capacity limited transient short-term store (STS) that can hold a fixed number of items for a short time before they are transferred to a more permanent long-term store (LTS). Items in STS are always perfectly retrieved. But in LTS, a search is necessary and this search may fail. Items in STS are maintained by rehearsing, or recirculating the items through a rehearsal buffer before they decay or are replaced by other incoming items. The longer an item is kept in STS, the higher is the probability of being transferred into LTS. In this sense, the model is similar to that postulated by the consolidation theory.

When an item enters STS, there is some probability that it will not enter the rehearsal buffer. To account for the spacing effect, it

may be assumed, as did Atkinson and Shiffrin (1968), that if an item is in the buffer when re-presented, it will not be re-entered into the buffer. The other possibility is to assume that an older item in STS has a higher probability of being replaced by an incoming item and that a repeated item changes the status of that item to be the most recent one and hence having a longer duration of residence in STS. This latter explanation is identical to the consolidation theory, less the commitment in the physiological processes.

This no-re-entry mechanism for the spacing effect was also favored by Greeno (1970) after examining a number of alternatives. In Greeno's (1970) words, "S sometimes simply turns off the processor that transfers items to long-term memory, or at least attenuates his rate of processing" (p. 584). According to him, the probability of this happening is particularly high when the item being re-presented is still in S's short-term memory.

Both Greeno (1970) and Atkinson and Shiffrin (1968) are more specific than the forgetting models concerning what happens to a P_2 of a massed repetition. The postulate that S stops processing, or rehearsing, a repetition of a recently presented item is readily testable. The amount of processing for a given item can be indexed by the time spent for studying a given item. If we let the S pace the study rate himself, we should observe a shorter study time in P_2 of a massed repetition. One such experiment was performed by Mackay (1969). In a continuous paired-associate learning situation, Ss received two presentations of each of the noun-noun pairs and were tested later for retention. In each presentation, a pair is either

presented alone or presented after its stimulus member had been shown for anticipation. After two such presentation trials for a given TBRI, there is a test which is an anticipation trial alone. IPI was varied from 0, 1, 4, to 8 intervening items. RI was also varied from 2, 4, to 10 items. Presentation rates, both for study and test trials, were paced by each S himself.

If we let T_i stand for a paired-associate anticipation trial and R_i for a trial in which the stimulus-response pair is shown, there are four different sequences of presentations, $T_1R_1T_2R_2T_3$, $R_1T_2R_2T_3$, $T_1R_1R_2T_3$, $R_1R_2T_3$. Ignoring whether the first presentation of a pair is preceded by its conventional paired-associate anticipation, T_1, the first two sequences are simply the RTRT procedure and the last two the RRT, as they are known in the "miniature experiment" tradition (Estes, 1960). In these situations, IPI refers to the distance between R_1 and either R_2 or T_2, if there is a T_2, and RI that between R_2 and T_3. The resulting R_2 study items were collapsed over RIs and are plotted in Figure 2, as a function of IPI, separately for the two conditions.

In both conditions, R_2 study time increased with increased IPI. The $R_1T_2R_2T_3$ condition was further broken down into two situations: one with correct anticipations at T_2 and the other with incorrect anticipations. Items in this latter situation can be taken as being in the forgotten state and hence should receive more processing than items in the learned or short-term state. In the Mackay (1969) experiment, this is in fact the case. The average R_2 study time for the incorrect items was constant at about 4.3 sec for every IPI. For the correct items, the average time was also constant at about 2.5 sec

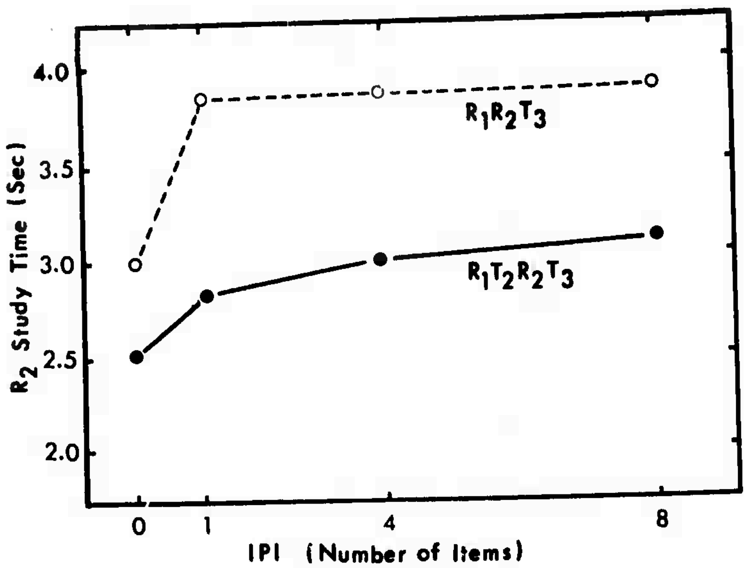

Fig. 2. R_2 study time as a function of IPI (from Mackay, 1969).

across all IPIs. The increasing trend of the $R_1T_2R_2T_3$ curve in Figure 2 was caused by an increasing number of items that failed to be retrieved and hence an increased averaged study time.

Thus, from the data in the $R_1T_2R_2T_3$ situation, the condition for additional processing of a TBRI is failure of retrieval of that item from memory, be it short-term or long-term memory. There are also certain other conditions that are sufficient to cause further processing, as suggested by data in the $R_1R_2T_3$ situation. In $R_1R_2T_3$, the average R_2 study time is much longer than that in $R_1T_2R_2T_3$. The only difference between the two is in whether there is an intervention of a test trial between R_1 and R_2 that provides S information regarding how well his memory for a given item is. Without this, S seems to further process items in a rather indiscriminate fashion. Despite additional R_2 study time, the $R_1R_2T_3$ condition is inferior to $R_1T_2R_2T_3$ in T_3 performance. This fact is rejective of the idea that T_3 performance

improves with increasing R_2 study time. Another evidence that supports this conclusion is that the study time function for $R_1R_2T_3$ asymptotes at IPI = 1 but the spacing function is still in the rise when IPI is further increased. It is clear that study time alone cannot explain the spacing function. Rehearsal, in the sense of recirculating the TBRIs through the rehearsal buffer (Atkinson & Shiffrin, 19), are not consistent with these data. Knowledge of the memorial status of a given item at R_2 must result in some different kind of processing during R_2 for the $R_1T_2R_2T_3$ items. The coding theories which we shall now turn to focus on just this problem.

<u>Locus P_2: Coding Theories</u>

In none of the theories examined thus far is there a distinction made between an experimenter-determined nominal TBRI and the <u>S</u>-determined functional TBRI. Failure in making this distinction leads to the implicit assumptions that what enters the <u>S</u>'s memory is the nominal TBRI and that a re-presentation of a TBRI necessarily constitutes a repetition of that item in the memory system.

There is a great amount of evidence against these assumptions. Underwood (1963) showed that in a learning situation, not all of the experimenter-defined stimulus, the nominal stimulus, is utilized by the <u>S</u>. The <u>S</u> selects from the nominal stimulus whatever is necessary for performance in a given task to be his stimulus, or the functional stimulus. For example, in a paired-associate learning situation involving letter trigrams or any compounds as stimuli, the <u>S</u> was rarely found to use all of the components contained in a compound as his

stimulus unless he is forced to do so. Thus, according to Underwood, the S's representation of a stimulus is far from being identical with the nominal stimulus designated by the experimenter.

This stimulus selection phenomenon is undoubtedly one of the best established facts in verbal learning today. A great amount of effort has, therefore, been channeled to discovering rules for selection rather than selection per se. Variables affecting stimulus selection have been found with considerable success. Among them are meaningfulness of stimulus components constituting the nominal stimulus (Cohen & Musgrave, 1964), spatial position (Postman & Greenbloom, 1967; Wichawut & Martin, 1970), and saliency of each component (Rabinowitz & Witte, 1967), to name a few. An extensive review of the stimulus selection process was recently given by Richardson (1971).

On the theoretical side, an attempt to distinguish between the stimulus as an ensemble of elements and the utilization of some of them on any given learning trial was made in as early as 1935 by Guthrie. This relationship between the sum and the some was later formalized as statistical sampling by Estes (1950). Viewing in this way, variation of the functional stimulus from trial to trial is ensured. With the introduction of a fluctuation property of the elements (Estes, 1955), an even wider variation is resulted.

In extending the stimulus selection phenomenon and the stimulus sampling fluctuation idea, Martin (1968) adduced the stimulus encoding variability hypothesis. The idea of encoding, or generating a code, from a nominal stimulus is due to Lawrence (1966). In essence, the Martin hypothesis states that a given niminal stimulus can be perceived

or encoded variably from one occasion to another. This variation could be the variation in selecting the nominal stimulus elements or variation in the encoding, in the sense of generating a memorial representation, of a selected element or set of selected elements.

Thus, according to the encoding variability theory, the letter 'A' may mean one thing, that is, have one code, when it appears in a poker hand and mean another, when it appears in front of a noun, and still another in some other environment. Encoding of homographic or homophonic stimuli provides another example. The encoding of the word 'pitcher' varies from occasion to occasion,either as a fluid container or as a ball player.

In relation to the spacing of repetitions phenomenon, there are at least two general types of coding theory. One is selective, the other additive.

<u>Selective encoding</u>.--The selective encoding theory, as proposed by Greeno (1967), assumes that any given TBRI has associated with it a number of codes from which the <u>S</u> selects one as a memorial representation. These codes have different properties. Some of them are 'good' codes, in the sense that they will last for a long time, long enough to be called permanent in a given experimental situation. The other are 'bad' codes. A bad code may be retrievable for a time, but will be lost eventually. On any given trial, either a good or a bad code can be selected, each with some probability. With short IPIs, the probability is higher that a bad code, if selected at P_1, survives at P_2 and hence there is no need for selecting another code. With a longer IPI, the probability that another code will have to be selected is higher if the

P_1 code is a bad code which may not last as long as the given IPI. In this way, longer IPI items have two opportunities in the selection, and hence a better chance of getting a 'good', permanent code.

The selective encoding theory runs into the same difficulty as the multistate Markov forgetting theory. That is, having a good code is tantamount to having an item permanently in the long-term state. The theory does not predict a reduced spacing effect beyond some optimal IPI.

One way to get around this is, as in the forgetting models, to assume that a permanent code need not be literally permanent. It may be lost with longer RIs. As an advantage over the forgetting models, it does not seem to be more complicated to assume a given TBRI to have associated with it a number of potential codes different in 'life expectancies,' which may range from very short to very long. A repetition can be assumed to reinstate the life expectancy to its maximum if a code is still in the memory system. If a code is lost, a new code will be selected, as a result of a repetition, from among the potential codes. The expected duration of this new code, will be equal to the mean duration of all potential codes. From these assumptions, we obtain a number of interesting predictions.

Suppose a given TBRI, $\underline{X}$, has associated with it $\underline{k}$ potential codes, C_1, C_2, ..., $C_{\underline{k}}$. The probability of randomly selecting one of these $\underline{k}$ codes, $P(C_i)$, is $1/\underline{k}$. Associated with each C_i is a temporal duration D_i such that $0 < D_i < \infty$. The units of D_i is in $\underline{T}$, which may be seconds in rehearsal preventing activity or number of intervening TBRIs. The distribution function of D_i can be assumed rationally to

approximate, or be approximated from, retention functions. The exact nature of this distribution function is not relevant here, however.

After a duration of aT, the probability that X is still represented in memory is

$$R(X;\ aT) = \sum_{i=1}^{k} P(C_i;\ D \geq aT). \tag{1}$$

$R(X;\ aT)$ is simply the proportion of C_i having D_i equal or greater than aT.

If IPI = bT, and $D_i < bT$, then at P_2, the code generated at P_1 is forgotten and as a result, another code will be selected to represent X in memory. The expected duration of this new code for X will be the average duration of all codes, E(D), if sampling with replacement is assumed. However, if $D_i \geq bT$, then at P_2 there is no need to make another selection since the P_1 code is still there. As a result of P_2, the code will last another D_i from P_2, or $D_i + bT$ from P_1. Thus with a P_2, and IPI = bT, the probability that X is still in the memory system at RI = aT is

$$R(X;\ aT,\ bT) = \sum_{i=1}^{k} P[C_i;\ D_i \geq (aT \ \& \ bT)] + [1-R(X;bt)][R(X;aT)], \tag{2}$$

where

$$1-R(X;bT) = \sum_{i=1}^{k} P(C_i;\ D_i < bT).$$

Substituting (1) and the above equation in (2), we obtain

$$R(X;\ aT,\ bT) = \sum_{i=1}^{k} P[C_i;\ D_i \geq (aT \ \& \ bT)]$$

$$+ \sum_{i=1}^{k} [P(C_i;\ D_i < bT)][\sum_{i=1}^{k} P(C_i;\ D_i \geq aT)]. \tag{3}$$

The first term to the right hand side of the equation is the probability that a code lasting longer than both IPI, $\underline{bT}$, and RI, $\underline{aT}$, is selected at P_1. At P_2 the 'life expectancy' of this code is renewed for another D_i. The second term is the probability for the following case. A code lasting less than IPI, $\underline{bT}$, is selected at P_1. At P_2, the code can no longer support memory for $\underline{X}$, and therefore, another selection is necessary. In order to retain the item for the next interval, $\underline{aT}$, a code with a $D_i \geq \underline{aT}$ must be chosen. This last condition is the same as that expressed in (1).

With very long RI, the function $R(\underline{X}; \underline{aT}, \underline{bT})$ asymptotes at its lowest level. This asymptote level is determined by the IPI. Within the limit of the maximal value of D_i, the longer the IPI, the greater will be the asymptote. $R(\underline{X}; \underline{aT}, \underline{bT})$ is thus determined, interactively, by IPI and RI. The function increases with increasing IPI, but decreases with increasing RI. This interaction yields a maximal spacing effect at various RI when IPI = RI. With a fixed RI, the two terms on the right in (2) or (3) reach their maximum when $\underline{aT} = \underline{bT}$, irrespective of the D_i distirbution that will be assumed. And at shorter RIs, shorter IPIs are more effective than longer ones, and vice versa. Thus we obtain from this model also the crossover effect found by Peterson et al. (1962).

This modified selective coding theory seems promising in fitting a variety of data. But data fitting is not the only criterion in assessing a theoretic system. We have to consider also the correspondence between theoretical entities and their defining conditions, as well as that between assumptions and empirical laws. On these later criteria, the theory encounters problems.

First, what constitutes a code? There is ample evidence showing that a stimulus gives rise to a myriad of reactions within the receiving organism. These reactions can be visual, acoustic, conceptual, associative, or any combination of them. We shall refer to these reactions as features, or attributes (Underwood, 1969). If each of these features constitutes a code, then a given stimulus will be represented by more than one code. This runs counter to what is assumed in the theory, namely, that a given TBRI is represented by one code at a time. If a code is equated with the conglomerate of these features, the second question arises. Are these features memorized or forgotten in an all-or-none fashion as a group?

There is evidence showing that forgetting of a code is not all-or-none. First, when an item fails to be recalled, partial information about that item is still available (Brown & McNeil, 1966). Second, with proper cueing, items otherwise not recallable are recalled (Tulving & Pearlstone, 1966; Bahrick, 1969). Items recognizable but yet not recallable provide another example (Mandler, Pearlstone & Koopmans, 1969). Third, when an error is made, either in recall or recognition, there tends to be a systematic relationship between the correct item and the erroneous item. For instance, the two may be acoustically similar (Conrad, 1964; Wickelgren, 1965a), or associatively or semantically related (Underwood, 1965; Anisfeld & Knapp, 1968). An item can be correctly recalled but incorrectly ordered in the output sequence (Wickelgren, 1965b). These different sources of evidence all indicate that there is some residual of a code that enables the emission of a nonrandom error.

Without changing the formal structure of the theory, it is possible to overcome this last problem. It can be assumed that a good code is a code that may 'support retention' (Greeno, 1967) for a long time whereas a bad code may not. The key word here is 'support retention.' When a code no longer supports retention, it can be that the code is lost from memory as described earlier or that the code is still present but some of its discriminating features are lost or become confused with features of other codes so that a correct response cannot be made from it (Kintsch, 1970). Forgetting in this later sense is the same as that assumed in the multi-component theory of the memory trace of Bower (1967).

With both interpretations of the term 'support retention,' the Mackay (1969) data can be readily explained. In the $R_1T_2R_2T_3$ condition, whenever a correct response could be given at T_2, there was no further code selection. But whenever a response failed to be correctly recalled, there was a code re-selection, and hence R_2 study time was increased. In the $R_1R_2T_3$ condition, there was no opportunity to find out whether a code is still able to generate a correct response. If the code was still in his memory, he may just utilize the time available to him rehearsing that same code. Despite this extra R_2 study time, performance at T_3 for this condition cannot be any better than that in $R_1T_2R_2T_3$ because of having one less opportunity in getting a good code.

Regarding the optimal spacing effect at RI = IPI prediction, the data fail to support it. For every RI, the spacing function is still in the rise when it passes the point where IPI= RI.

Additive encoding.--This version of the coding theory does not assume forgetting of an old code as a necessary condition for selecting a new

code, as is the case in the selective version. Instead, encoding variation is determined by various other factors. This variability in encoding a TBRI has been the concern of various theorists ranging from those whose primary aim is to explain perceptual phenomena to those in the learning area. Among the factors proposed to account for this variability are mental set (Gibson, 1941), stimulus context (Robinson, 1932), randomness (Estes, 1950), and context and randomness (Bower, 1971). These factors can be grouped as those concerning the stimulus environment and those concerning the "internal state" of the S at the time he reads in the stimulus.

The randomness idea belongs to the latter category. That is, it is taken to refer to the S's moment-to-moment fluctuation in his "stream of consciousness" (Bower, 1971, p. 15). Fluctuation as such represents a failure in controlling the S's information processing activity rather than an uncontrollable random process. Robinson's stimulus context factor belongs to the first category but it can be shown that this stimulus environment factor can be incorporated into the concept of "internal state." Thusly, all these factors can be reduced to one, namely, the state of the S at the time he encodes the stimulus.

As stated earlier, when a stimulus is presented to the S, there is a myriad of reactions occurring inside him. Let S_i be the stimulus and the set $[r_i]$ stand for the reactions. The set $[r_i]$ is activated by S_i. This relation can be written as

$$S_i \longrightarrow [r_i], \qquad i = 1, 2, \ldots\ldots, n \qquad (4)$$

Each of the elements $(r_{i1}, r_{i2}, \ldots\ldots, r_{im})$ in the set $[r_i]$ can be thought of as features, components, or dimensions of an encoding. The

view here is consonant with Bower's (1967) multi-component and Wickens' (1970) multi-dimension concept of the memory trace.

The set $[r_i]$ is taken as the theoretic entity that remains in the S's memory system. Let the set $[r_c]$ stand for the effect of, or whatever is left over from, preceeding respondings. At the time when S_i is presented, the set $[r_c]$ is invariably incorporated into the set $[r_i]$. Thus, the encoding responses can be schematized by elaborating (4) as

$$S_i \longrightarrow [r_i, r_c], \qquad i = 1, 2, \ldots, n \tag{5}$$

This conglomerate $[r_i, r_c]$, then, constitutes one encoding. The set $[r_i]$ is the stable part which is directly activated by S_i. The set $[r_c]$ is variable from one occasion to another. It is this set $[r_c]$ that determines encoding variability. For example, the phonic signal /san/ gives rise to a set of $[r_{/san/}]$. Suppose $[r_{c:sun}]$ is the memory trace of something related to sun, and $[r_{c:son}]$ something related to son. We have

$$[r_{/san/}, r_{c:sun}] = \text{sun},$$

and

$$[r_{/san/}, r_{c:son}] = \text{son}.$$

This $[r_c]$ effect is what has been variously referred to as state, mental set, expectation, etc. It is also taken as the same as what is called the context effect. For any context to have an effect, it must be responded to by the S before the nominal stimulus is attended to. Thus the Robinson context is at bottom the $[r_c]$ in this formulation.

In relation to the spacing effect phenomenon, the implication of the theory is this. If two repetitions are spaced apart, the chances

are higher that the second context will be different from the first. This results in a higher probability for the TBRI to be encoded differently in its second occurrence.

There are two possible ways in which differential encoding can be assumed to improve memory. One is by assuming that two different encodings can result in the storage of two different codes of the same TBRI (Madigan, 1969) and thereby increase the likelihood of a successful retrieval. The other possibility is by code enrichment, in the sense that more information is added into the existing code and hence the code is strengthened or enriched with more retrieval cues (Melton, 1967, 1970). The first view attributes the spacing effect to what happens at the stage in which a code or a representational response (Bousfield, Whitmarsh, & Danick, 1958) is generated. But according to the second view, the effect lies at the stage in which this code or representational response is associated with other contextual cues. These contextual cues may range from temporal tags (Yntema & Trask, 1963), adjacent TBRIs (Melton, 1967), to any free association response that may occur to the code (Underwood, 1965).

Another distinction between multiple codes and code enrichment views lies in whether recognition of a repeated item is a necessary condition for the spacing effect. According to the multiple-code view, recognition of a P_1 code at P_2 is not necessary for the establishment of another code. On the contrary, failure of recognition may provide a more favorable situation for having a different code, and thereby provides the basis for the effect of spacing. The code enrichment view implies the opposite, that is, code enrichment is possible only when a P_1 code is retrieved for enrichment at P_2.

By assuming multiple codes in differential encodings, implications of the additive encoding theory can be explicitly drawn. The theory assumes the amount of improvement from spaced repetitions to be a function of the probability, a, of getting a different code at P_2, and this probability is in turn determined by variations in the contexts of the two occurrences. It follows that if a is kept constant by manipulating the contexts, the spacing function becomes flat or at least the slope of the function is attenuated.

Keeping a context constant is possible only theoretically. However, it is not impossible to keep the context variation at its minimum. By doing this, the resulting a will approach zero and thus prevents any improvement resulted from two spaced repetitions. On the other hand, if the two contexts are very different, a can be brought up to close to unity and thus ensures improvement for all repetitions, be they massed or spaced, within some limit of IPI and RI.

There is evidence that variations in contexts can be manipulated to effect variations in encodings. Light and Carter-Sobell (1970) presented ambiguous nouns with adjectives that biased the interpretations (meanings) of these nouns at P_1. At P_2, these nouns were paired with either the same adjectives, different adjectives but biasing toward same interpretations, or different adjectives biasing toward different interpretations. Same adjectives were found to produce the highest number of hits and lowest number of false positives. Different adjectives that induced different meanings of P_2 produced the worst recognition performance, that is, fewest hits and most false positives. In three experiments, corrected recognition scores (per cent hits minus per cent

false positives) are in the order of 60% to 73% for the same adjectives condition. For the different-adjective-different-meaning condition, the scores range from 20% to 30%. With different adjectives but same meanings, the score is 45%, which is in about the same order as that for items presented alone for recognition at P_2. Apparently, failure of recognition in the different-meaning condition is due to having very different P_2 codes, rather than forgetting of the P_1 codes.

With respect to the spacing effect, Madigan (1969) manipulated the associative modifiers accompanying nouns presented for free recall, as well as the IPI between two presentations of a noun. A noun was either paired with the same modifiers or different modifiers but biasing toward the same interpretation of the noun in both presentations. IPI was varied from 0, 4, 8, to 16 intervening items. In a non-cued recall test, both same modifier and different-modifier conditions exhibit the same usual spacing effect. But when recall was cued by both modifiers the spacing function of the different modifier condition become flat. For the same-modifier condition, the flat function was not observed. Instead, a usual spacing function was obtained and the performance level reached by longer IPIs was far higher than that reached by the different-modifier condition. This seems counter to what the additive encoding theory would predict.

In a similar design but with very short lists in a Peterson-Peterson situation, Garskof (1969) also obtained this same result. That is, different adjectival modifiers inducing similar meanings of a noun produced a flat function, and same adjectives effected a usual spacing curve that starts at a lower level than the different-adjective

condition but rises to a much higher level at a longer IPI. In the Garskof experiment, included was also a condition in which different adjectives induced different meanings. This condition produced the lowest level of performance and the function declined when IPI was increased.

In none of these experiments, however, was the context functionally separated from the TBRI. When a noun is paired with a modifier and the modifier is not treated as a separate and independent TBRI, as is the case in the experiments of Madigan (1969) and Garskof (1969), what constitutes a functional TBRI becomes obscure. The modifier-noun pair may be represented as just one single code and thus it is further subjected to contextual variations. That the same-modifier condition displays a spacing effect agrees completely with this interpretation.

The Present Experiments

What is needed is a situation in which a context affects the encoding of a TBRI but yet remains itself a separate item. The experiments that will follow were designed to achieve this purpose.

In the present experiments a modified Shepard and Teghtsoonian (1961) continuous recognition memory paradigm will be employed. On any given trial, a pair of TBRIs, instead of just one, will be presented and the Ss are to respond to each of them separately. Pairing two TBRIs on a single presentation offers an opportunity to manipulate the nature of one item so as to affect the encoding of the other item. Having the Ss respond to each of them separately avoids the possibility that the two items are encoded as a single functional unit. The continuous recognition

memory situation also offers both an opportunity to precisely control IPIs and RIs and an opportunity to follow closely what happens at P_2 and P_3, instead of just P_3.

CHAPTER II

METHODS

Experiment I

Design of Lists

A list consisted of 350 pairs of common words. Some of the words occurred once, some twice, and some three times. The total number of different words in a list was 350, of which 86 were presented twice. The remaining 264 words were equally divided between those presented once and those presented three times. Thus, the numbers of new words and repeated words were equated.

If a word was repeated, the distance between any two occurrences, be it between the first and the second or the second and the third, varied from one intervening pair to 150 intervening pairs. In the entire list, no pair was repeated, that is, a given repeated word always re-occurred with a different word. Of all 350 pairs, one fourth contained two new words as pair members, one fourth contained two repeated words and the other half contained one new and one repeated word. For the pairs that had both new and repeated words as pair members, the spatial positions of the two words were counterbalanced.

As judged by E, half of the 350 pairs had pair members that were, within a pair, associatively or semantically related. The other half bore no such relation.

There were 126 experimental pairs in Experiment I. An experimental pair had a homograph (word with multiple meanings) as one member

and a "context" word as the other member, that is, a word that would or would not bias the homograph toward one of its meanings. For brevity in references, the homograph member will be called the <u>target</u> word and the other member the <u>context</u> word. Context words that are related to one meaning, X, of the target word will be called Context X, and those related to the other meaning, Y, of the same target word will be called Context Y. Context words that have, seemingly, no relations with either meaning of the target word are considered neutral and will be referred to as Context N.

A target word occurred three times in the list, each with a different context word. The order of the contexts in these three occurrences defined a context condition. There were seven such conditions: XXX, XXY, XYX, XYY, XXN, XYN, and NNN. All seven context conditions were interlockingly built into the list. Example pairs for some of the conditions are displayed in Table 1.

TABLE 1

EXAMPLE PAIRS IN SELECTED CONTEXT CONDITIONS*

Order of Occurrence	Context Condition					
	XXY		XYN		NNN	
First	CONTAINER	PITCHER	FOOTBALL	COACH	COFFEE	BANK
Second	MUG	PITCHER	PASSENGER	COACH	TAILOR	BANK
Third	BASEBALL	PITCHER	WINE	COACH	NARROW	BANK

*In these examples, the target word is always the right hand member of the pair. In the experiment, half of the target words were on the right and half on the left.

The interval, IPI, between the first and the second occurrences of a target word was varied, in all context conditions, from 8, 20, to 60 intervening pairs, and that between the second the third occurrences, RI, was fixed at 60 intervening pairs. Thus, in a list, there were seven context conditions and three IPI conditions. Within each of these 3 x 7 = 21 combinations of context and IPI there were two target words, one occupying the left position of the pair, for all three occurrences, and the other the right position. This resulted in 21 x 3 x 2 = 126 experimental pairs.

The first 56 pairs in the list were buffer pairs. No experimental pair occurred in this buffer. The two target words in each context-IPI combination were distributed so that one occupied approximately the first part of the list and the other the second part. The positions for the context-IPI combinations were fixed.

For each list so constructed, there was a yoked list that mirror-imaged its context conditions. Thus for an XXX condition in one list, the yoked list would have a YYY condition. In other words, all the X contexts were changed to Y and Y contexts changed to X in the yoked list. The neutral contexts remained the same for both lists. The target words were assigned twice between the IPI conditions and twice within a given IPI condition but among the seven contexts. The assignments were in such a way that no target word served in any context-IPI combination more than once. The total number of lists was 2 x 2 x 2 = 8 lists.

Materials

The 42 target words in Experiment I were drawn from the pool of homographs whose association norms had been collected by Perfetti,

Lindsey, and Garson (1971) or Kausler and Kollasch (1970). There were two criteria for selection. First, a homograph selected had only two mutually exclusive meanings, as indicated by the norms. Second, for each homograph, the bias for one meaning against the other was less than 80:20 (maximum 100:0; minimum 50:50).

The context and filler words were common words with one, two, or three syllables drawn from Thorndike and Lorge (1944). The frequencies of these words were at least 20 per million according to the same source. Only common nouns, verbs, and adjectives were included.

Procedure

Each list of 350 pairs of words were typewritten and ditto-duplicated to make copies of a 350-page, 2.75 x 8.50 in. booklet. Each page of the booklet contained two words, side by side in the middle of the page. The pairs were numbered from 1 to 350. For ease in handling, the booklet was divided into three parts. The first part contained 120 pairs, the other two contained 115 pairs each. The Ss were told to treat the three parts as one and to work continuously from one part to another without any stop.

The Ss were tested in groups of 3 to 8. Each of them was given a booklet and a two-page answer sheet. On the answer sheet, there were numbers from 1 to 350. Right next to each number there were three boxes. The first box contained the letters U and R. The other two were empty, and were purported to correspond to the two members of a pair.

The S's task was to turn the pages of the booklet over, one at a time, at his own pace. Upon seeing a pair of words on a page, he was to do two things on the answer sheet before turning to the next page. First, he was to indicate, by circling the letter U or R, whether the two words were semantically or associatively related. R means the two members of a pair are related while U means not. Second, he was to indicate how many times he had seen each of the two words before, in the two empty boxes, the right-hand word in the right box and the left-hand word in the left box. The number to be entered into each box was either 0, 1, or 2; 0 for a word that had never occurred before, 1 for once before, and 2 for twice before. The Ss were allowed to write in numbers bigger than these if they thought a frequency was more than 2.

Subjects

There were 128 Ss in Experiment I. They were both male and female University of Michigan students drawn from two sources: (1) Human Performance Center subject pool, and (2) those who responded to a subject-wanted advertisement run in the campus daily newspaper. Sixteen Ss were assigned to each list. Care was taken so that within each list the numbers of male and female Ss were equal. Each S was paid $1.50/hour for the service.

Experiment II

Design of Lists

The design of lists in Experiment II is essentially identical to that in Experiment I. However, the following variations were made. In Experiment II, the number of context conditions was reduced to three in

order that more observations per condition could be obtained from one S and from more portions of the list. The three conditions were XXN, XYN, and NNN. The list structure was the same as in Experiment I, except that XXX, XYX, and XXY conditions were changed, respectively, to XXN, XYN, and NNN. The XYY condition was simply dropped.

Within an IPI condition, a target word served three times at the same serial position, once for each of the three context conditions. As a result, the context conditions were rotated among all available positions within that IPI condition. The target words were distributed twice. In the second distribution, they were rotated, as groups, among the IPI conditions. As in Experiment I, each list had a yoked list, thereby producing a total of 3 x 2 x 2 = 12 lists.

Another difference between Experiment I and II is that within an IPI condition the serial positions for context conditions were fixed and target words varied in Experiment I whereas in Experiment II the serial positions of the target words were fixed but contexts varied.

Materials

There were 36 target words in Experiment II. The target words were chosen from the 42 homographs used in Experiment I. The context words to accompany the target words were also taken over and all the pairings, as paired in Experiment I, were maintained.

Procedure

In Experiment II, the pairs were typewritten on Kodak-Ektagraphic Write-on slides. Each slide contained a pair number on the top left hand corner. The two words of the pair were placed one on top of the other,

and were typed single spaced. The 350 slides were shown one at a time at a 9-sec rate. During this 9-sec period, the S was to do the same thing as in Experiment I, that is, make a relation judgment and two frequency judgments. The Ss were tested in groups of 8 to 12. The total duration for the whole experiment was 52.2 min.

In Experiment II, the Ss were explicitly told that at any given point in the list, the chance of getting a new word was 50 per cent and that the maximum number of times a word could have appeared earlier was 2.

Subjects

There were 96 Ss. They were both male and female University of Michigan students drawn from the same two sources as in Experiment I. Eight Ss were assigned to each list. Care was also taken so that within each list the numbers of male and female Ss were equal. Each S was paid $1.50/hour for the service.

CHAPTER III

RESULTS

Since Experiments I and II have basically the same design, the results from the two experiments will be reported together, side by side for comparison purpose. The order of presentation will be made with respect to the order of occurrences, that is, first, second, and third occurrences of the TBRIs.

First Occurrences

General false positive rate.--When a TBRI was shown for the first time, it was new (N_1) as defined in the experiments. However, the item may be judged by the S as having occurred before ('O_1'). These false positive (FP) responses are plotted in Figure 1. In the figure, the ordinate represents proportions of new items judged as old, $P('O_1'|N_1)$, and the abscissa blocks of 10 successive pairs. Each co-ordinate is the average of all $P('O_1'|N_1)$ in a given block. The number of N_1 ranged from 7 to 14 for all except one block. The first block of 10 pairs contained 18 new items.

In Figure 3, two things are apparent. First, the two experiments produced essentially identical FP rates. This "identity" even holds in their peaks and valleys, especially in the first 21 blocks. The presentation rate in Experiment I was self-paced by each S, but in Experiment II the rate was 9-sec per pair and Ss were informed of the likelihood of seeing a new item at any point in the list. Obviously,

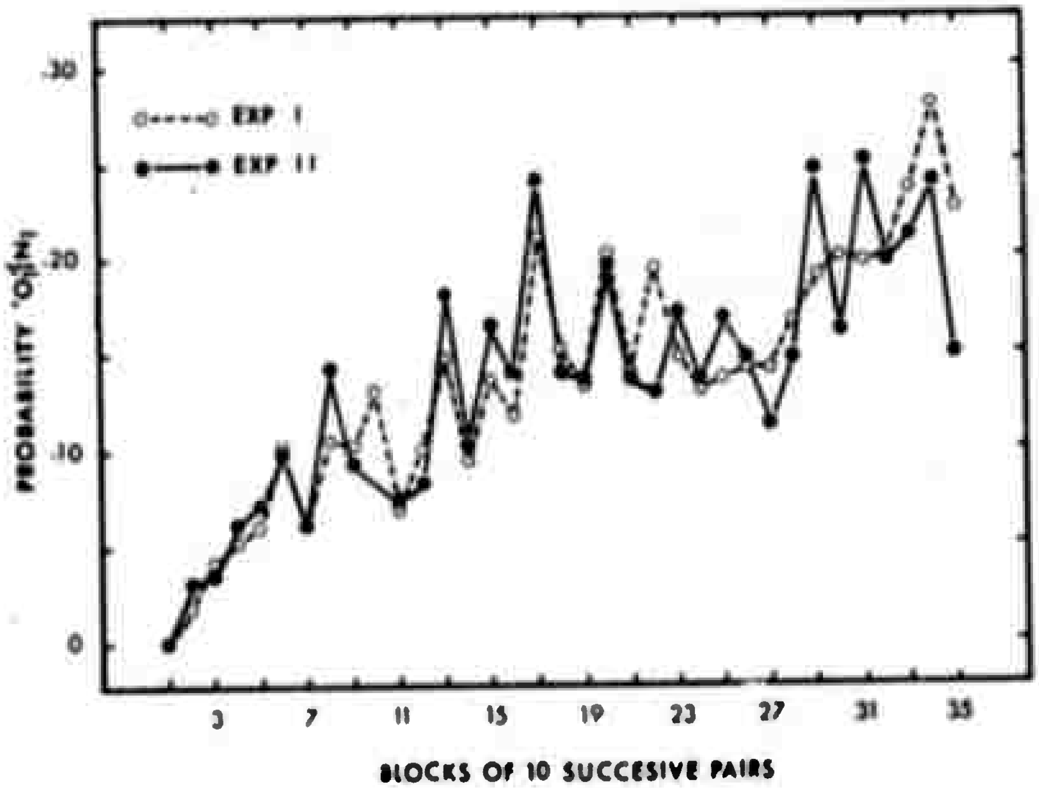

Fig. 3. Proportion new items judged as having occurred before as a function of blocks of 10 successive pairs.

the two presentation rates did not produce any FP differences, nor did the knowledge about the composition of the list. The overall FP rates are 12.93% and 12.77%, respectively for Experiments I and II.

This indifference to rate of presentation in FP responses was also observed by Melton, Sameroff, and Schubot (1967), but the rates involved in their experiments were 6-sec and 3-sec per item. The observed "identity" in peaks and valleys suggests that FP rate is item specific. This might have been due to the relation between a new item and its preceeding items (see Underwood, 1965; Anisfeld & Knapp, 1969). Experiments I and II had itentical filler items for most parts of the lists.

Second, the build-up of FPs is rapid in the first few blocks and rises to about 20% to 25% in the last few blocks. There is no sign that FP rate has reached its asymptote, even when more than 300 pairs of items have been presented. This observation is similar to that obtained by Martin and Melton (1970), with high-meaningfulness nonsense syllables.

False positive rates for context and target items.--Recall that all context items occurred just once in the list, therefore, any non-zero frequency judgment given to any of these items is a FP. The FP rates for these items, summarized by collapsing over IPI conditions, are tabulated in Table 2.

TABLE 2

PERCENTAGE OF ONCE OCCURRING CONTEXT

ITEMS JUDGED AS REPEATED

Context Condition	Experiment I: Ordinal Position of Occurrence P_1	P_2	P_3
XXX	8.98	13.43	21.10
XXY	9.64	14.97	16.67
XYX	9.25	10.29	21.09
XYY	10.23	17.06	22.01
XXN	8.47	13.80	14.88
XYN	8.72	9.77	21.48
NNN	10.29	11.72	19.40
	Experiment II		
XXN	11.88	13.93	19.55
XYN	9.63	9.45	20.35
NNN	12.24	16.10	19.13

P_1, P_2, and P_3 in Table 2 denote the first, second, and third occurrence of a target word that a context word was paired with. From P_1 to P_3, there is a systematic increase in FP rate for all conditions, $F(2,254) = 86.06$, $p < .005$ for Experiment I, and $F(2,190) = 43.37$, $p < .005$ for Experiment II. This may be due to the fact that the actual serial position of P_1 is earlier than that of P_3. That FP rate increases with increasing order of occurrence of a new item has already been shown in Figure 3.

In Experiment I the $F(2,254)$ ratio for the effect of context condition is 2.41 ($p < .10$). The interaction between context and ordinal position is also significant, $F(12,1524) = 3.26$, $p < .005$. For Experiment II, the effect of context is $F(2,190) = 6.20$, $p < .005$, and that of the context-position interaction is $F(4,380) = 4.12$, $p < .005$.

In Experiment II, the effect of the position of a context word within a pair (the top or bottom member) was also analyzed. The resulting $F(1,95)$ ratio is less than 1, despite the fact that the pairs having the context words as bottom members tended to occur later in the list. This is because no attempt was made to counterbalance position in a pair and position in the list.

Nevertheless, of interest are the following two observations. First, in both experiments, the FP rate reached by all conditions at P_3 are high. These rates are among the highest averages plotted in Figure 3. It appears that there is an increased tendency to judge a new word old when it is paired with an occurred-twice-before target word. Second, the XXX condition did not produce a FP rate higher than other conditions, in spite of their having more related words (both

target and context) preceding them. The FP rates for neutral contexts at P_3, (XXN, XYN, and NNN) are not any lower than the rest, except that for XXN of Experiment I, which is the lowest of all.

In Table 3 presented are the FP rates for the target items. The entries for Experiment I in the Table vary substantially. The range is

TABLE 3

PERCENTAGE OF NEW TARGET ITEMS JUDGED AS REPEATED

Context Condition	IPI 8	IPI 20	IPI 60
Experiment I			
XXX	11.72	16.02	15.23
XXY	8.21	10.55	8.99
XYX	14.85	7.81	10.16
XYY	21.88	9.37	9.77
XXN	8.60	10.94	15.23
XYN	21.10	12.11	12.11
NNN	13.67	14.06	15.24
Experiment II			
XXN	8.33	9.90	12.24
XYN	11.46	9.90	11.72
NNN	8.59	11.20	11.98

from 7.81% of Condition XYX at IPI = 20 to 21.88% of Condition XYY at IPI = 8. The rates are different among context conditions, $\underline{F}(6,762) = 3.44$, $\underline{p} < .005$, and among IPI conditions, $\underline{F}(2,254) = 3.33$, $\underline{p} < .05$. The interaction between contexts and IPIs is also significant,

$F(12,1524) = 4.17$, $p < .005$. For Experiment II, FP rates for target words in different IPI conditions vary slightly, $F(12,190) = 3.00$, $.10 > p > .05$. The variations among different context conditions are not significant, $F(2,190) < 1$. Different positions of a target word within a pair produced a difference of 3.36%. The lower positions resulted in more FPs than the upper. This difference, though small, is statistically significant, $F(1,95) = 9.27$, $p < .005$.

This heterogeneity of FP rates for the different conditions complicates interpretation of recognition responses on subsequent occurrences of the same TBRI. There is evidence that once a new item has been judged old, the probability then becomes higher for the second occurrence to be judged as repeated, compared to items correctly judged as new in their initial occurrences (Melton, Sameroff, & Schubot, 1967; Martin & Melton, 1970). In the present experiments, when an FP response was made to an item, the probability that the same TBRI would be judged new in the second occurrence is very small. The conditional probabilities for such instances, in Experiment I, are .04, .05, and .10, respectively, for IPI = 8, 20, and 60. For Experiment II, these three probabilities are .06, .08, and .11.

Second Occurrences

In Experiment I, the data for recognition responses and relational judgments at P_2 were collapsed over the different P_3 context conditions, thus reducing the seven context conditions to three, XX-, XY-, and NNN. Included in XX- and XY- are the YY- and YX- conditions. For Experiment II, there was no such collapsing. The probabilities of judging a TBRI as

repeated when it occurred for the second time are plotted, for each condition, against IPIs in Figure 4.

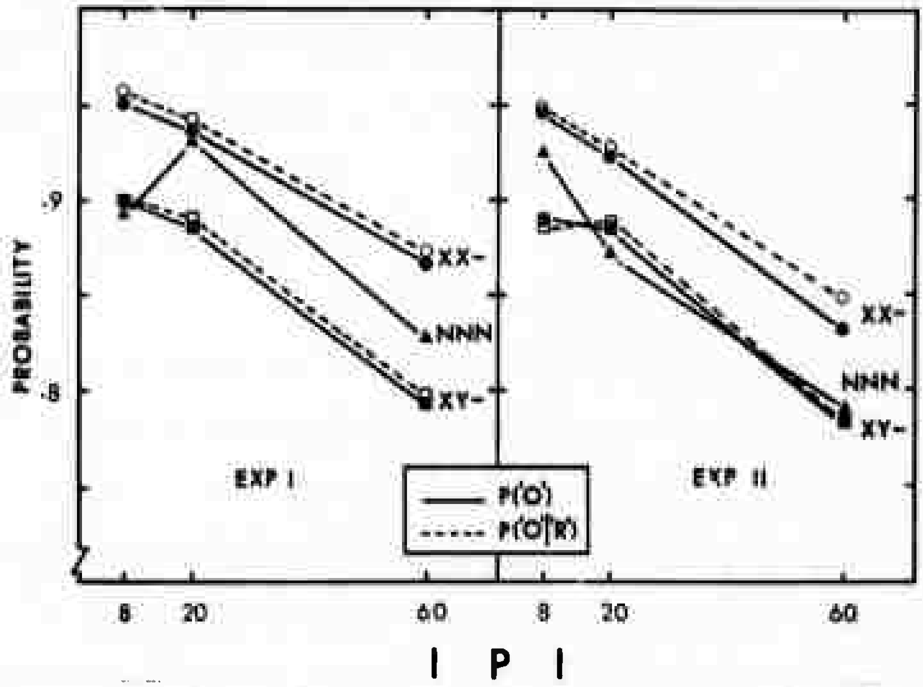

Fig. 4. Unconditional and conditional probabilities of judging an item repeated in its second occurrence as a function of P_2 context and IPI.

The solid lines represent the unconditional P_2 recognition probabilities. For both experiments, there is a systematic decline over IPIs for all three context conditions. Substantially greater amount of forgetting was produced when IPI was increased. This decline is highly significant statistically: For Experiment I, $F(2,254) = 41.13$, $p < .005$, and for Experiment II, $F(2,190) = 39.25$, $p < .005$. When the P_2 context was changed, as in the XY- condition, recognition probability was significantly lower. In a test of XY- against XX- in Experiment I, the resulting $F(1,127)$ ratio is 40.33, $p < .005$. P_2 recognition probability for the NNN condition is between XX- and XY- in Experiment I. But in Experiment II, this is true only for the shortest IPI, IPI = 8.

For longer IPIs, the NNN and XY- conditions do not appear to be different. The $F(2,190)$ ratio for the effect of the three context conditions in Experiment II is 5.79, $p < .005$. Unlike the FP responses for target items at P_1, position of a target word in a pair did not produce any significantly different effect, $F(1,95) = 1.09$.

In Figure 4, also plotted are the conditional probabilities of saying an item was repeated given that the item was judged as being related to its context word. The two types of probabilities, conditional and unconditional, are essentially the same. P('O'|'R') and P('O') are very close to each other, for all context-IPI conditions. Contingency analyses were done separately for each pair of data points in Figure 4. For Experiment I, the only significant chi-squares are those of the XX- condition at IPI = 8, $\chi^2(1) = 11.01$, $p < .005$, and of the same XX- condition but IPI = 20, $\chi^2(1) = 4.92$, $p < .05$. The next highest chi-square value is 1.59, $.10 < p < .25$, for XX- at IPI = 60. None of the chi-squares in the XY- condition are significant, the biggest being 1.85, $p > .25$, at IPI = 20. The significant chi-squares obtained in the XX- condition are very likely due to relatively small numbers of observations in the non-recognition category and the fact that each S contributed to more than one cell of the contingency table.

For Experiment II, the highest chi-square value is 7.93, $p < .005$, for XX- at IPI = 60. All the rest are less than unity; the biggest value being .23, $p > .50$.

To assess the effect of P_2 context, unconditional probabilities of judging a pair as having related pair members are plotted in Figure 5, together with their probabilities conditionalized on recognition judgments.

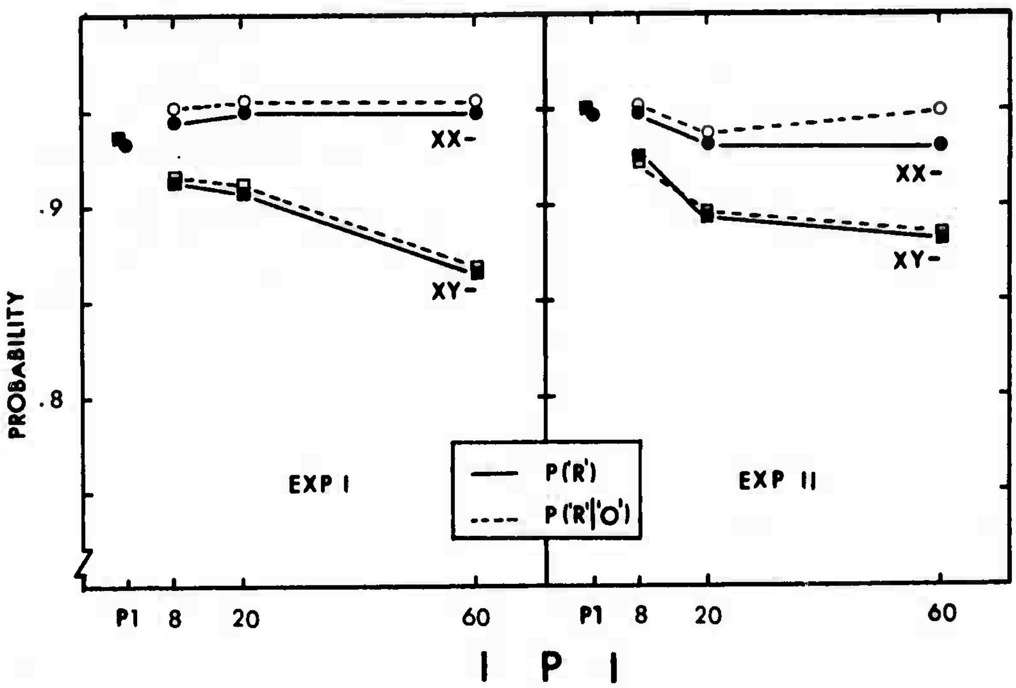

Fig. 5. Unconditional and conditional probabilities of judging a pair as having related pair members, as a function of context and IPI. (The two points to the left of each panel are probabilities of a 'related' judgment at P_1.)

For comparison purpose, probabilities of a 'related' judgment at P_1 are also plotted in the same figure.

In Figure 5, the independence between relational and recognition judgments, as reflected by P('R'|'O') = P('R'), is duplicated. When there is a change in context (XY-) at P_2, probability of 'related' judgment is significantly lowered. Compared to the XX- condition, the resulting $\underline{F}(1,127)$ ratio is 47.38, $\underline{p} < .005$. IPI has an effect on XY- but not XX-. The interaction between IPI and context gives an $\underline{F}(2,254)$ of 6.28, $\underline{p} < .005$. Probabilities of a 'related' judgment in XY- decreased with increasing IPIs. For XX- the effect is not as clear-cut; there is a slight drop of such probabilities in Experiment II but not in Experiment I. In Experiment II, the effect of context is $\underline{F}(1,95) = 7.32$, $\underline{p} < .005$, and of IPI, $\underline{F}(2,190) = 3.01$, $.05 < \underline{p} < .10$. The interaction

is not significant, $F(2,190) < 1$. Nor is the effect of position in a pair, $F(1,95) < 1$. The insignificant position effect implies that the context word has the same effect irrespective of whether it is placed above or below the target word. Not shown in Figure 5 are relational judgments for the NNN condition. Averaged over the occurrences, the probabilities of 'related' judgments for the three IPI conditions in increasing order are .14, .14, and .10 in Experiment I, and .07, .08, and .09 in Experiment II.

Thus, changing context at P_2 lowers both recognition probability and 'related' judgment probability, and these two probabilities are mutually independent. This observation constitutes a paradox, in the sense that changing context suppresses recognition but yet when the context effectiveness is indexed by relational judgment, recognition is independent of this judgment.

Third Occurrences

Table 4 contains the percentages of target items judged as being repeated at P_3. Apparently, percentages of recognition are very high for all conditions, and these different conditions do not seem to produce any substantially different recognition performance. Although the NNN condition of Experiment I does show a sign of the spacing effect, it fails to be affirmed in Experiment II.

Reservations must be made in interpreting these data. First, there appears to be a ceiling effect in these data, and this may have masked all discriminabilities. Second, as noted in the First Occurrences section, different conditions involve items having different

TABLE 4

PERCENTAGE OF TARGET ITEMS JUDGED AS BEING REPEATED AT P_3

Context Condition	IPI 8	IPI 20	IPI 60
Experiment I			
XXX	98.04	98.44	96.48
XXY	95.31	94.14	95.70
XYX	96.87	96.87	97.26
XYY	97.26	96.09	96.87
XXN	97.26	95.70	97.65
XYN	96.09	97.65	93.35
NNN	89.45	96.48	96.09
Experiment II			
XXN	93.49	96.09	94.27
XYN	95.57	95.57	97.66
NNN	95.05	93.23	90.89

confusability with the filler items in the list, as reflected in different FP rates. This is particularly the case in Experiment I. Thus, what is needed is some measure that not only avoids this ceiling effect but also the effect of differential FP rates.

There are two measures that satisfy the first criterion. One is judged frequency of occurrence of a given item at P_3. This will be later referred to as F_3. The other is the probability of giving an F_3 of greater than 1, $P(F_3 = 2+)$. For the second criterion, one

possible way out is to exclude all target items having FP responses at P_1 from the analyses. This results in the elimination of up to approximately 20% of all target items for some conditions. Coupled with the first criterion, the resulting measures are $F_3|'N_1'$ and $P(F_3 = 2+|'N_1')$. These two measures can be further conditionalized on recognition at P_3 to become $F_3|'N_1' \& 'O_3'$ and $P(F_3 = 2+|'N_1' \& 'O_3')$.

One serious drawback for the correction for FP just described is that $'N_1'$ can be null in some condition for some individual S. When this happens, $F_3|'N_1'$ and $P(F_3 = 2+|'N_1')$ become indeterminate. In the experiments, there are many such cases. Hence, the corrected measures are restricted to the marginal sums collapsed over Ss in the conditions involved. By such doing, the range of the statistical tests that can be applied becomes very limited.

P_3 frequency judgment results from Experiment I are plotted in Figures 6 and 7. In Figure 6 plotted are: F_3 in the top row three panels (panels A, B, and C); $F_3|'N_1'$ in the middle row three panels (panels D, E, and F); and $F_3|'N_1' \& 'O_3')$ in the bottom row three panels (panels G, H, and I). They are plotted as a function of context conditions and IPIs. For comparison purpose, the XXN, XYN, and NNN conditions are plotted in the same panels. They all have a neutral P_3 context but different P_1 and P_2 contexts. The three panels in the middle columns, as well as the three panels in the right-hand column, have the P_3 context varied but those of P_1 and P_2 held constant. Figure 7 is for $P(F_3 = 2+)$, $P(F_3 = 2+|'N_1')$, and $P(F_3 = 2+|'N_1' \& 'O_3')$. The groupings are the same as in Figure 6.

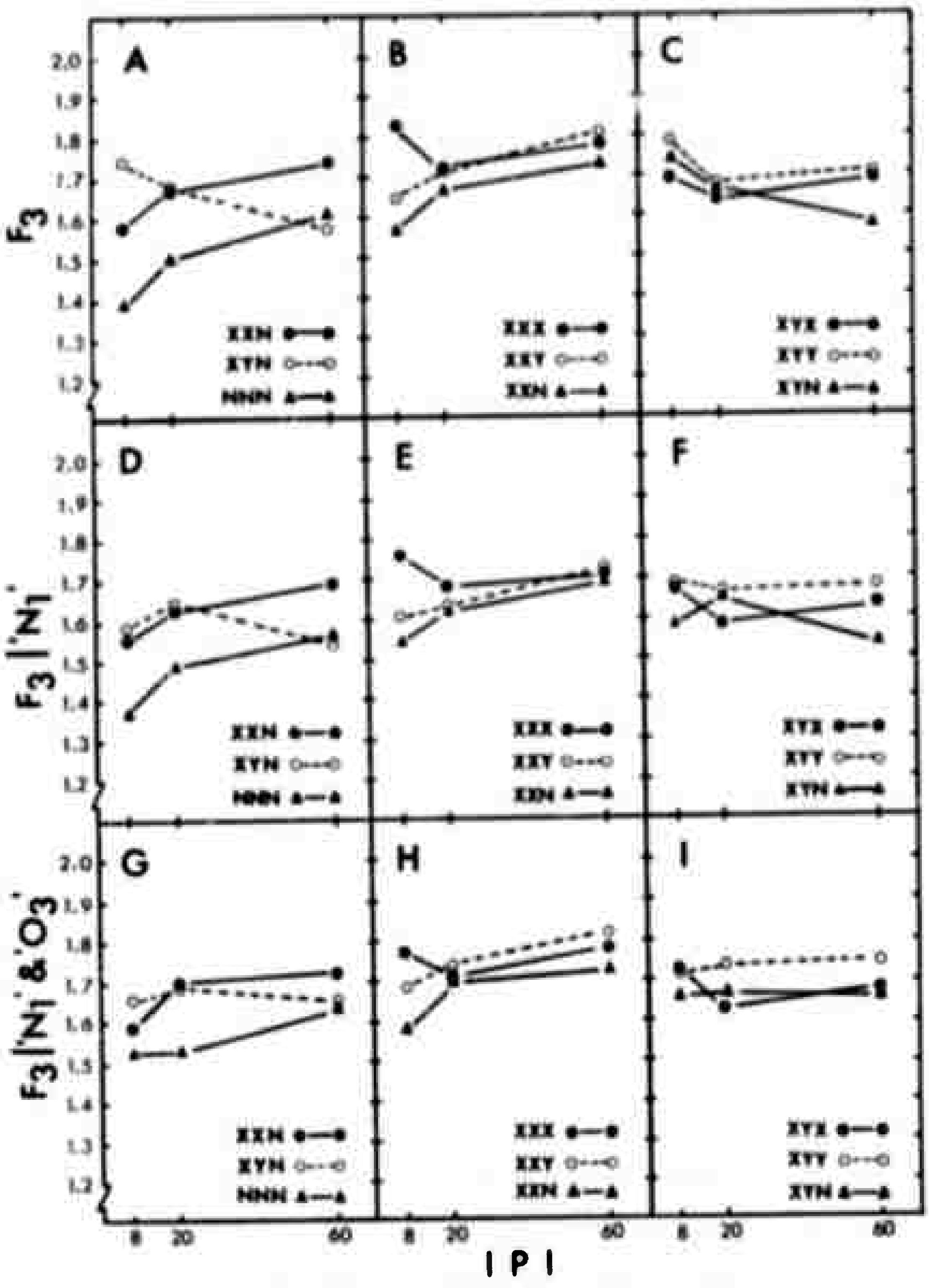

Fig. 6. Frequency judgement at P_3, F_3, as a function of context and IPIs. (F_3 in Panels D, E, and F is conditionalized on 'N_1'; in Panels G, H, and I, F_3 is conditionalized on 'N_1' and 'O_3'.)

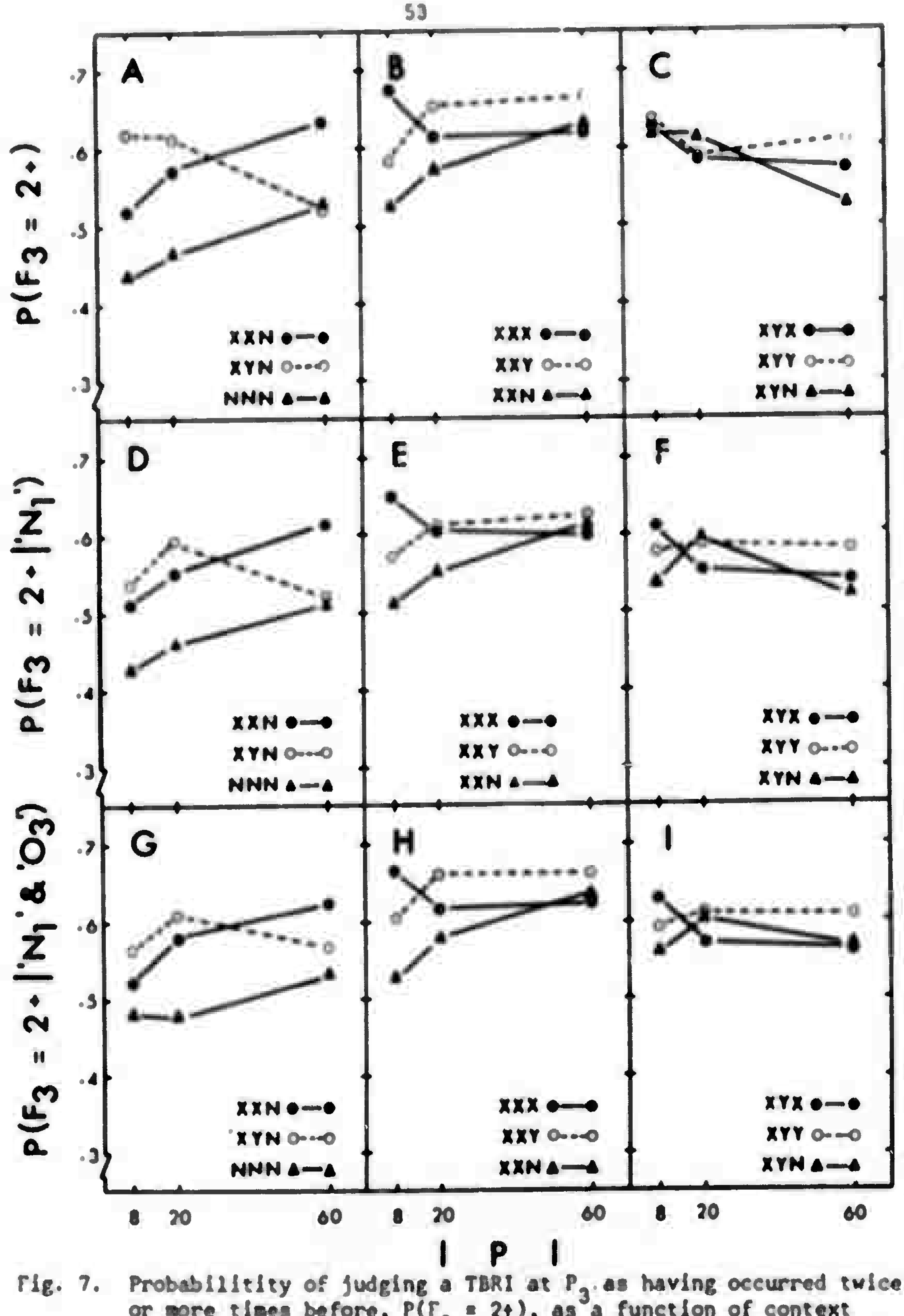

Fig. 7. Probabilitity of judging a TBRI at P_3 as having occurred twice or more times before, $P(F_3 = 2+)$, as a function of context and IPI. ($P(F_3 = 2+)$ in Panels D, E, and F is conditionalized on 'N_1'; in Panels G, H, and I, $P(F_3 = 2+)$ is conditionalized on 'N_1' and 'O_3'.)

The pictures that emerge from Figures 6 and 7 are very similar. The XXN, XXY, and NNN conditions consistently exhibit the usual effect of spacing. Judged frequencies in these conditions increase with increased IPI, irrespective of whether they are conditionalized on 'N_1', or 'N_1' & 'O_3', or not conditionalized at all. The three conditions have very similar curves, the only difference being that XXY and XXN have higher judged frequencies than NNN at all IPIs. In Panel A of Figure 6, the $F(2,254)$ value for the effect of context is 17.98, $p < .005$. For IPI, the value is 2.45, $.05 < p < .10$. However, the interaction between IPI and context is very significant, $F(4,508) = 6.86$, $p < .005$. It is apparent in Panel A that while XXN and NNN increase with IPI, XYN decreases. This decreasing trend of XYN disappears when FP items are eliminated (panels D and G). In Panel A of Figure 7, the $F(2,254)$ value for context is 13.89, $p < .005$. For IPI, the value is 1.50, $p > .10$. But for the interaction between context and IPI, $F(4,508) = 4.33$, $p < .005$.

The effect of IPI and P_3 context on the XX- conditions is shown in Panels B, E, and H in Both Figures 6 and 7. The usual spacing effects are observed in conditions having P_3 context different from those in P_1 and P_2, XXY and XXN. The effect for XXX is apparently different. XXX starts out with a very high frequency at the shortest IPI and the frequency declines as IPI increases. Another surprising finding in these three panels is that a differently biasing context at P_3 resulted in as high or higher frequencies than a neutral context. For statistics in Panel B of Figure 6, context produces an $F(2,254)$ of 7.65, $p < .005$, IPI an $F(2,254)$ of 4.10, $p < .05$, and the context-IPI interaction an $F(4,508)$ of 2.57, $p < .05$.

For Panel B of Figure 7, the statistics are these: Context, $\underline{F}(2,254) = 5.67$, $\underline{p} < .005$; IPI, $\underline{F}(2,254) = 1.96$, $\underline{p} > .10$; interaction between context and IPI, $\underline{F}(4,508) = 2.77$, $\underline{p} < .025$.

The effects of IPI and P_3 context in the XY- conditions are shown in Panels C, F, and I in both Figures 6 and 7. In general, the resulting curves are lower than those of the XX-. In Panel C of Figure 6, the effect of IPI is significant, $\underline{F}(2,254) = 4.07$, $\underline{p} < .05$. However, when FP items are excluded, the decreasing trends disappear. This can be seen in Panels F and I. Collapsing over the three IPIs, the effect of context is not significant, $\underline{F}(2,254) = 1.92$, $\underline{p} > .10$. Nor is the interaction between context and IPI, $\underline{F}(4,508) = 1.55$, $\underline{p} > .10$. Nevertheless, XYY condition has a slightly higher judged frequency than the XYX when IPIs are long. This tendency is consistent either before or after the elimination of FP items.

For Panel C of Figure 7, the statistics are: Context, $\underline{F}(2,254) < 1$; IPI, $\underline{F}(2,254) = 3.12$, $\underline{p} < .05$; and interaction between these two, $\underline{F}(4,508) = 1.00$.

To summarize the results at P_3 of Experiment I, conditions XXN, XXY, and NNN exhibit the usual spacing effect. That is, judged frequencies in these conditions increase when IPI is increased. The XXY condition has as high or slightly higher judged frequencies than XXN, which are in turn higher than NNN. Condition XXX is very different. It starts out with higher judged frequencies at a short IPI, but declines when IPI is increased. For the XY- conditions, the frequencies are generally lower than the XX- and are indifferent to variations in IPIs.

Frequency judgement data for Experiment II are plotted in Figure 8. The three panels in the top row (A, B, and C) contain F_3, $F_3|'N_1'$, and $F_3|'N_1'$ & $'O_3'$. In the lower three panels (D, E, and F), plotted are $P(F_3 = 2+)$, $P(F_3 = 2+|'N_1')$ and $P(F_3 = 2+|'N_1'$ & $'O_3')$. Like in Experiment I, the two measures, F_3 and $P(F_3 = 2+)$ yield very similar curves. But in Experiment II, exclusion of FP items affects little the trends and orderings of the curves.

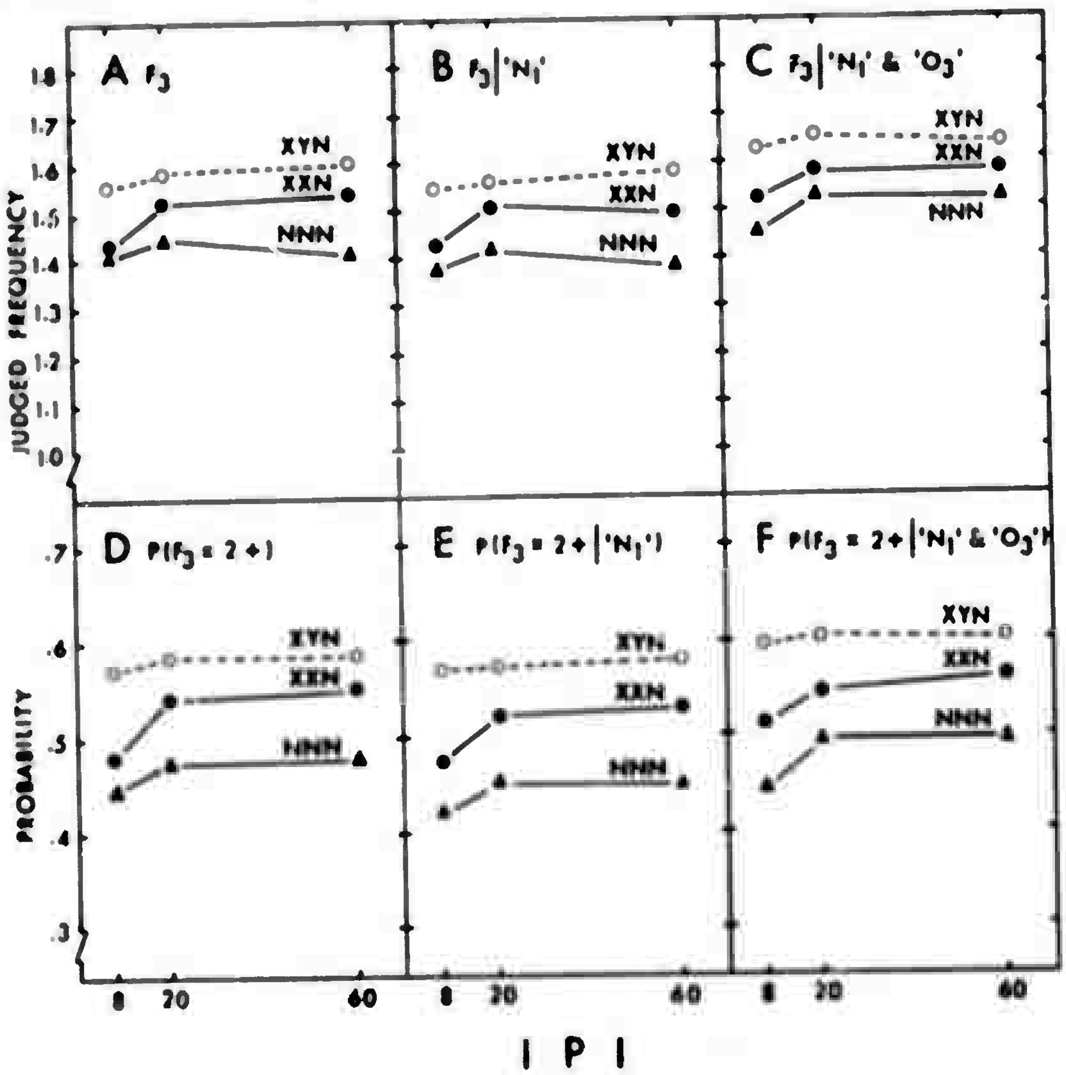

Fig. 8. F_3 and $P(F_3 = 2+)$ as a function of context and IPI. (In Panels B and E, the two measures are conditionalized on $'N_1'$; in Panels C and F, they are conditionalized on $'N_1'$ and $'O_3'$.)

In Panel A, judged frequencies for XYN are high and increase very little with increased IPIs. The NNN condition has the lowest frequencies but the same flat trend. XXN produces frequencies in between XYN and NNN and shows a usual spacing effect. However, the effect seems to reach an asymptote at IPI = 20.

In Panels A and B, there appears to be a drop in judged frequency for NNN at IPI = 60. However, the drop disappears in other panels, where the measure is either $P(F_3 = 2+)$ or F_3 conditionalized on 'O_3'. In Panel B, a slight drop for XXN at IPI = 60 is also observed. Like NNN, the drop disappears when F_3 is conditionalized on 'O_3'. Thus, for XXN and NNN at very long IPIs, there is a tendency for judged frequency to be either 0 or greater than 1.

For statistics in Panel A, the effect of context has an $F(2,190)$ of 18.26, $p < .005$. For IPI, $F(2,190) = 1.98$, $p > .10$. The interaction is not significant. In Panel D, $F(2,190) = 18.57$, $p < .005$ for context, and $F(2,190) = 1.80$, $p > .10$ for IPI. The interaction is also not significant.

Analysis of variance was also performed for each context condition separately. For XYN in Panel A, the effect of IPI is infinitesimal $F(2,190) < 1$. For XXN, IPI has a significant effect $F(2,190) = 3.26$, $p < .05$. For NNN, the $F(2,190)$ ratio of IPI is less than unity. The statistics for the effect of IPI in Panel D are: XYN, $F(2,190) < 1$; XXN, $F(2,190) = 2.25$, $.10 < p < .05$; and NNN, $F(2,190) < 1$.

In all of the analyses of variance in Experiment II, position of a target word within a pair was treated as a separate variable. Position

effect is highly significant in all but one analysis. In both XXN and XYN the bottom member of a pair resulted in higher average judged frequency than the upper member. For the upper members, the averages are 1.42 and 1.54, respectively for XXN and XYN. The two averages for the lower members are 1.58 and 1.64. The $F(1,95)$ values for position effect are 20.18, $p < .005$, and 7.51, $p < .01$ in XXN and XYN, respectively. As reported earlier, position within a pair is confounded with position in a list in such a way that the bottom positions tend to occupy later positions in the list. Either position in a pair or position in a list or, of course, both can produce this effect. But there is ground to believe that the effect is due to position in a pair rather than position in a list. In the NNN condition, the effect of position in a pair is almost absent, $F(1,95) < 1$, despite the fact that the two within-pair positions differ in locations in a list.

The spacing effects observed in XXN and NNN are not as pronounced as in Experiment I. In Experiment I, the functions are still in the rise even when IPI is extended to as long as 60 intervening pairs. In Experiment II, an asymptote seems to be reached at IPI = 20. In both experiments XYN has a flat and very similar function. Collapsing over IPIs, the average judged frequency for XYN, excluding items having FPs at P_1, in Experiment I is 1.59 and in Experiment II, the average is 1.57. The two averages are very close to each other. However, both the XXN and NNN conditions in Experiment II produced lower judged frequency than their counterparts in Experiment I. In Experiment I, the

two averages, collapsing over IPIs and excluding items having FPs at P_1, are 1.62 and 1.47, respectively for XXN and NNN. In Experiment II, the two averages are 1.47 and 1.39. Thus, procedural variations between the two experiments affect simultaneously XXN and NNN but not XYN.

CHAPTER IV

DISCUSSION

The NNN condition represents a control situation in which nothing is altered to affect the encodings of the TBRIs involved. The effect of spacing of repetitions, as measured by frequency judgments, was observed. When IPI is increased, judged frequency is also increased despite the constancy in the TBRI's nominal frequency. This finding is confirmative of the results obtained by Hintzman (1969) and Underwood (1969b), thus indicating that the homographic stimuli used and the experimental procedure involved in the present experiments did not alter the condition that produces the spacing effect in any way.

The spacing effect has been demonstrated in recognition memory with a variety of measures. In the oft-cited Hintzman (1969) experiment, the dependent measure is _recognition time_, and in the experiments by Kintsch (1966) and Underwood (1969b), the measure is _recognition frequency_. In the present experiment, the measure is _judged frequency_. Recognition frequency of meaningful words in a continuous recognition task is usually very high and any differential performance that may result is masked by the ceiling effect, as is the case in the present experiments. Recognition time and frequency judgment represent more refined measures than recognition frequency. That is, both recognition time and frequency judgment involve a more stringent criterion in response classification than recognition frequency.

In relation to the spacing effect, there is evidence showing that what affects frequency of recall also affects frequency judgment and the two functions are essentially identical (Madigan, 1969; Underwood, 1969b). This indicates that both frequency of recall and frequency judgment are but measures of the same genotypic effect resulting from spacing of repetitions. It also follows that any theory that is proposed to explain the spacing effect as measured by frequency of recall or recognition must also be applicable to frequency judgment.

It is the explanation of this spacing effect, particularly that offered by the multiple-code version of the additive encoding theory, that the present experiments are concerned with. According to the multiple-code theory, the effect of spacing of repetitions is caused by the increased probability of encoding the same TBRI differently in its second occurrence. Exactly what is meant by a different encoding is left unspecified. However, it is not unreasonable to assume that a different encoding means extracting a second meaning from a word. This differential encoding possibility is greatly facilitated when the TBRIs are words having multiple meanings such as homographs used in the two experiments just reported.

The theory stipulates that in the NNN condition, as IPI increases, the probability that a second occurrence of a TBRI will be encoded differently is also increased, supposedly due to a more different context. More specifically, if a TBRI is encoded as X at P_1, the likelihood that this same TBRI will be encoded as Y at P_2 is increased if the interval between P_1 and P_2 increases. In NNN, since there was no attempt to detect the encodings at both P_1 and P_2, empirical evidence pertaining to this genotypic phenomenon is not available.

However, readily testable by the data in other conditions are two corollaries of the multiple-code theory. Within some limits of IPI and RI, these two corollaries are:

Corollary A: If a TBRI is encoded as X at P_1 and Y at P_2 for all IPIs, the spacing function is flat and maintains a level equal to the highest that NNN can reach.

Corollary B: If a TBRI is encoded as X at both P_1 and P_2 for all IPIs, the spacing function is flat and maintains a level equal to the lowest of NNN.

For the multiple-code theory to hold, both Corollaries A and B must be shown to be the case. Rejection of any of the two corollaries necessarily rejects the set of assumptions from which they are derived, namely, the multiple-code theory.

In Condition XY- of both experiments, the opportunity for getting a different encoding at P_2 is deliberately boosted for all IPIs, by providing the S with a different P_2 context. Induction of a different encoding as such is effective, as indicated by the high frequency (in the order of 85% or more) of observing the relatedness between the changed P_2 context and the target words. In NNN, such frequency is about 10%. According to Corollary A, the XY- conditions will have a flat and high spacing function. In Figures 6, 7, and 8, after the exclusion of FP items, the flat-function prediction is confirmed. In Figures 6 and 7 (Experiment I), the three XY- conditions do maintain a level equal to the highest of NNN. However, in Figure 8 (Experiment II), the highest of NNN is still far below XYN and there is no sign

that NNN will eventually reach XYN as the curve for NNN appears to asymptote at IPI = 20.

According to Corollary B, the three XX- conditions should display a flat and low spacing function. In these conditions, variability in encoding is reduced to its minimum and thusly the ground for an improved performance with longer IPIs is also minimal. As is obvious in Figures 6, 7, and 8, these predictions are contradicted by the data. The XX- conditions (with the exception of XXX) display a regular spacing effect very similar to that of NNN. Furthermore, the performance level of XX- is higher than NNN at every IPI.

Such an observation is rejective of Corollary B, and hence the necessity of rejecting the idea of encoding multiplicity in the sense of getting alternative meanings of a TBRI as the cause of the spacing effect. Getting different meanings of a TBRI does improve memory. But improvement resulting from spaced repetitions appears not to be produced by getting multiple codes for a given TBRI. That the XX- functions are the usual spacing function suggests strongly that encoding stability, rather than variability, is a necessary condition for the spacing effect to occur.

There are reasons to believe that encodings in the NNN condition are rather constant meaningwise. First, the spacing function of NNN is very similar to XXN, a condition in which encoding constancy is ensured. Second, what affects XXN also affects NNN. In Experiment II, due to procedural variations involved, judged frequency in XXN is generally lowered and the spacing function asymptotes at a shorter IPI.

This same effect is also present in NNN, but not in XYN. In XYN, these variations did not produce any differential effect.

In other conditions, there is also evidence indicative of persistence of a P_1 code. In the XY- conditions, although there is a reduction in P_2 recognition frequency, the magnitude is only about 8% from XX-. This magnitude is surprisingly small vis-a-vis the frequency of recognition which is in the order of more than 85% for XX-. Thus, even when the P_2 context is deliberately altered to successfully induce a different P_2 code in most cases, this alteration effects little in preventing a P_1 code. Furthermore, a changed context is not as effective as an original context. This is indicated by the reduced frequency of observing the relatedness between a target word and its second, changed context, as shown in Figure 5. This inhibitive effect of a P_1 encoding on P_2 context effectiveness indicates that there is a tendency to perpetuate an encoding rather than changing it. When a TBRI is encoded in the same way twice, an altered context, introduced at P_3, is ineffective in preventing the recurrence of that encoding. On the contrary, a biasing context, be it altered or same, boosts judged frequency. This can be seen in Figures 6 and 7 by comparing XXX and XXY to XXN.

Outside the domain of the present data, attempts to induce a particular meaning of a homograph by a preceding word have not been successful. Recognition of a homograph induced by a preceding context word, to have a different meaning than when it first appeared in a study trial is not any different from having no inducing context preceding it (Perfetti & Goodman, 1970). In paired-associate transfer

situations involving two dimensional stimuli, Ss remained utilizing the same dimension if they could choose to do so when going from a first list to an interfering second list (Goggin & Martin, 1970; Schneider & Houston, 1968).

We are thus in a position to observe improved performance with multiple encodings. But multiple encodings as defined in the present context, getting alternative meanings of a TBRI, is apparently not likely to be the cause of the spacing effect. In a great number of experiments in which the effect was found, the stimuli used were not, in most cases, readily encoded as either X or Y. If encoding multiplicity is to be held responsible for this effect at all, it has to be multiplicity along dimensions other than that between alternative meanings.

As discussed in Chapter I, the additive encoding theory can be thought of as having either multiple codes or just one single code enriched with retrieval cues. The multiple-code view is clearly not supported by the data. The code enrichment view is not contradicted, however. The observation that the XX- conditions are superior to NNN is consistent with this enrichment view. That is, the superiority of XX- is due to a constant amount of associative cues (the context words) added to a given code, besides the amount of other contextual cues which increase with increasing IPIs. These contextual cues may be temporal tags (Yntema & Trask, 1963), other adjacent TBRIs (Melton, 1967), or any moment-to-moment fluctuation of ideational responses (Bower, 1971).

In the present experiments, there are also three other interesting observations. First, probability of observing the relatedness between a target and a context word at P_2 for XY- decreases with increasing IPI (see Figure 5). Although this observation constitutes another piece of evidence against the idea that with increasing IPI the likelihood of getting a different code from the same TBRI increases, the explanation of the observation itself is difficult to make. It cannot be due to variation in encoding in a third dimension, that is, a TBRI may have been encoded as Z, instead of just X or Y. For if this were the case, a similar decline in the frequency of a related judgment should be observed in the XX- condition. As can be seen in Figure 5, the function for XX- is essentially flat across IPIs. Nor can it be the consolidation of a P_1 code that results in the increased interfering effect on getting a new, changed code. If this were the case, the function for XX- should increase instead of being flat with increased IPI.

Second, there appears to be a paradoxical relationship between context and recognition. Recognition is impeded when the context is altered but when context effectiveness is indexed by relational judgment, this relational judgment is independent of recognition judgment. That recognition is dependent on context is clearly demonstrated in Figure 4, and in a number of other experiments (e.g., Light & Carter-Sobell, 1970; Tulving & Thomson, 1971). Relational judgment is also dependent on context, as shown in Figure 5. When a context is changed from X to Y, the frequency of observing the relatedness between the target and the context word Y is reduced. That relational judgments and recognition

judgments are independent can only mean that a context can be effective without being judged as related. By dismissing relational judgment as a measure of context effectiveness, there is no longer a paradox.

Third, the effect of changing context on P_2 recognition is small, compared to those obtained by Light and Carter-Sobell (1970) and Tulving and Thomson (1971). The difference lies in that in their experiments, a study-test method was employed but in the present experiments an item was treated as both test and study. It appears that in this situation, Ss may explore more of the features to be encoded and thus reduce the amount of limitation imposed by the context. It also suggests that the recognition process is not only searching in memory for a stored code but also a search through all potential codes associated with a given TBRI.

CHAPTER V

SUMMARY AND CONCLUSIONS

Two experiments were conducted to test the variable encoding theory of the spacing effect. One version of the theory, the multiple-code version, states that the spacing effect is caused by a higher probability, associated with spaced repetitions, of getting a different code for a same TBRI in its second occurrence.

In the experiments, the distance between two repetitions and the contextual environment affecting probability of getting a **same** or different code were orthogonally varied in a modified Shepard-Teghtsoonian (1961) continuous recognition list. The target items were homographic stimuli and each of them was paired with either a biasing context word, that is, a word inducing a particular meaning of the target, or a neutral context word. The Ss were to indicate both the relatedness between a target word and its accompanying context word. This was intended to ensure the effectiveness of a biasing context and also to provide a basis to index this effectiveness. A target word occurred three times, each time with a different context word. The distance between a first and a second occurrence was either 8, 20, or 60 intervening pairs and that between second and third was always 60. The two biasing contexts of a given homograph car be denoted as X and Y, a neutral context as N. In Experiment I, a homograph could have occurred first with X, second with Y, and third

with N (denoted as XYN). There were seven such context conditions, namely, XXX, XXY, XYX, XYY, XXN, XYN, and NNN. In Experiment II, there were only three, XXN, XYN, and NNN. Experiment II was conducted to obtain more observations per condition per S and from more portions of the list. The dependent measure was judged frequency for each TBRI at each presentation.

The spacing effect was observed in NNN, XXN, and XXY. The XXX condition had the highest judged frequency but there was no increasing trend when IPI was increased. The XYX, XXY and XYN conditions did not show any effect of spacing. The functions were flat across all IPIs and were generally high.

Thus, it was concluded, multiple encodings of an item leads to higher judged frequency and hence a stronger representation of that item in memory. However, on the basis of the spacing effects found in the XX- conditions and their similarity to NNN, it was further concluded that encoding variability in the sense of getting alternate meanings of a TBRI is not the factor that produces the spacing effect. If variability in this sense had been the case, there should not have been any spacing effect in the XX- conditions.

Evidence was also adduced to suggest that in those situations where the spacing effect has been found, encodings of the TBRIs are rather stable. What is added may not be another code, but rather other cues associated to the code. When the distance between any two presentations is increased, so is the variation in contextual cues. These contextual cues may range from the momentary stream of ideational responses to

subjectively organized units of TBRIs (Melton, 1967). These contextual cues, if they become associated with a code for a TBRI, may serve to strengthen the code in memory and also facilitate its later retrieval.

APPENDIX

HOMOGRAPHS AND THEIR INDUCING CONTEXT WORDS

Homograph	Context X	Context Y
1. PITCHER	CONTAINER MUG SPOUT	BASEBALL CATCHER BATTER
2. BRIDGE	ROAD TUNNEL SUSPENSION	CARD POKER GAME
3. PALM	HAND THUMB PALMISTRY	LEAF TREE COCONUT
4. BANK	RIVER SHORE COAST	SAVING FINANCE MONEY
5. CELL	BIOLOGY AMOEBA GROWING	JAIL PRISON INMATE
6. YARD	GRASS GARDEN LAWN	ROD INCH MEASURE
7. COUNTRY	KINGDOM STATE NATION	RURAL FARM CITY
8. DRILL	DENTIST HOLE OIL	REPEAT PRACTICE MEMORIZE

Homograph	Context X	Context Y
9. SWALLOW	CHEW GULP EAT	BIRD FLYING GULL
10. MINE	YOURS OURS HERS	COAL COPPER ORE
11. ROW	COLUMN SEATS LINE	BOAT OARS CANOE
12. LEAN	VERTICAL SLANT SUPPORT	FAT MEAT BEEF
13. BOW	RIBBON HAIR GIRL	ARROW ARCHERY SHOOTING
14. ROCK	MUSIC CONCERT RHYTHM	SOIL MOUNTAIN GRANITE
15. WATCH	CLOCK TIMER WRIST	SEE LOOK OBSERVE
16. RULER	COMPASS DRAWING PENCIL	EMPEROR KING DICTATOR
17. RING	WEDDING DIAMOND ORNAMENT	PHONE BELL SOUND
18. CARDINAL	BISHOP CHURCH POPE	BLUEJAY ROBIN CHIRPING

Homograph	Context X	Context Y
19. CLUB	STICK WOOD BEAT	SOCIAL MEMBER PARTY
20. NAIL	FINGER TOE CLAW	BOLT HAMMER IRON
21. ORGAN	PIANO KEYBOARD HARP	ANATOMY BODY LUNGS
22. LEAD	FOLLOW AHEAD FRONT	METAL GASOLINE PIPE
23. SEAL	ANIMAL ZOO FLIPPERS	STAMP CLOSE TIGHT
24. TURKEY	MOSQUE PERSIA TURKS	POULTRY CHICKEN MEAL
25. PUPIL	DILATION RETINA	TEACHER STUDENT
26. COACH	ATHLETIC FOOTBALL	PASSENGER CARRIAGE
27. CABINET	KITCHEN CUPBOARD	GOVERNMENT PRESIDENT
28. COUNT	NUMBER TALLY	DUKE COUNTESS
29. FIRM	SOLID FIXED	BUSINESS CORPORATE

Homograph	Context X	Context Y
30. PRESS	SQUEEZE PUSH	EDITORIAL REPORTERS
31. FILE	CARPENTER SANDPAPER	SECRETARY RECORD
32. PEN	INK FOUNTAIN	FENCE PIGS
33. TABLE	DINING CHAIR	CHART SCHEDULE
34. NET	FISHING BUTTERFLY	GROSS INCOME
35. COURT	SUPREME JUSTICE	TENNIS BADMINTON
36. PLANT	FACTORY INDUSTRY	FLOWER GREENHOUSE
37. BOWL	ALLEY THROW	DISH SOUP
38. BARK	DOG YELP	BIRCH STEM
39. LIE	TRUTH TELL	SIT DOWN
40. BASS	GUITAR CELLO	TROUT FISH
41. POLE	FLAG HIGH	RUSSIAN PEOPLE
42. PRIVATE	PERSONAL PUBLIC	SARGEANT ARMY

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